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CHEMISTRY

AN

EASY INTRODUCTION

TO

CHEMISTRY

EDITED BY THE REV.

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WITH NUMEROUS ILLUSTRATIONS

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PREFACE

THE foundations of knowledge are only securely laid when habits of observation have been cultivated. The inquiries young persons frequently make are prompted by what may be considered instinct, and are generally suggested by that which is seen or handled. Hence parents and teachers, as far as practicable, answer with much care and patience these early thirstings after knowledge. To supply information in a form which it is hoped may be intelligible and interesting to all parties concerned in thus learning to read the ever-open book of nature, the following pages are issued. They are based upon a *First Book of Chemistry*, by Dr. Worthington Hooker, published in America, and are intended to convey information in respect to changes which are likely to attract the attention of young persons who observe and inquire. The book professes to be only an introductory one: this however may be quite consistent with an interesting and accurate one. It may amply satisfy some readers—it may be an incentive to further inquiries and deeper research with others. If in any case it proves acceptable, and conveys such elementary knowledge as must precede higher studies, it will thus subserve one important purpose in its publication.

PREFACE TO THE SECOND EDITION.

COMMUNICATIONS received from many who read the first edition expressed a hope that if a future edition were issued, certain alterations might be made, which would render the volume as well suited for educational as it was for domestic use. The suggestion has been adopted, and Mr. Walter T. Goolden, late Scholar of Merton College, Oxford, has contributed most materially to such changes in this edition as seemed likely to make the book acceptable where, in its original form, it was not expected to be introduced.

March, 1875.

PREFACE TO THE THIRD EDITION

IN this edition many corrections have been made and some few additions, which it is hoped will make the book more useful to teachers. The Editor has not thought it desirable to introduce Chemical Symbols, or add anything to the text which will alter its strictly elementary character.

W. T. G.

TONBRIDGE, 1883.

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CHAPTER I.

INTRODUCTION.

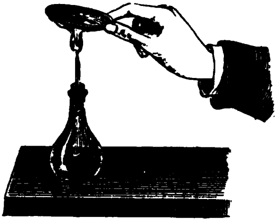
As you are about to learn something of the science of chemistry in this book, you are doubtless anxious to understand in a general way what that science treats of, before entering more particularly upon the detail; to get a rough idea at any rate of the aim and object of the chemist, which you too, as a student of chemistry, must keep in view as you proceed onward.

We look around and see that the world is made up of a number of substances which differ from one another in very many ways. It is the province of the chemist to study one particular kind of difference which exists between bodies, which perhaps you will best understand if you have a special example given as an illustration or sample of the whole class.

When a chemist examines a piece of chalk, for instance, he finds that it is not, as might be supposed, simply a piece of chalk and nothing else, but that he can obtain from it three other substances very unlike one another indeed. One is a gas which also forms part of the air we breathe; another is carbon or charcoal, and the third substance is a metal. Thus we see that a light gas, black charcoal, and a metal, can be extracted from white chalk, at first sight a very unlikely circumstance. Secondly, he finds that these three bodies are simple in themselves and cannot be broken up further, and he therefore calls them elements. Thirdly, he finds that by certain contrivances he can reunite these three bodies and form a substance identical with the chalk from which they were extracted.

Again, water is found to be composed of two gases, one the same that is in chalk, the other a gas sometimes used for filling balloons; these two gases unite to form water in every flame that burns, except in those of sulphur, phosphorus, carbonic oxide and one or two other substances. The water that is formed is not ordinarily visible, because it passes off into the air as gas, but that it is really formed can be demonstrated in various ways. For instance, if a cold spoon, or a metal cup containing ice and salt, as shown in Fig. 1, be held over a candle or gas flame, water as it passes off is *condensed*, that is, reduced from the gaseous to the liquid state, and gathers in drops upon the under side of the metal, even though soot may be deposited at the same time by the flame.

Fig. 1.



You may often notice too that when a bright kettle of cold water is placed over a gas flame, the outside of the kettle is covered with dew, which sometimes gathers in sufficient quantities to trickle down off the sides. This water is formed by the union of these two gases.

Fig. 2.

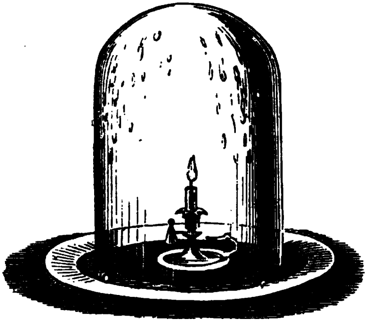


Fig. 2 illustrates this fact in another way. A candle is burnt under a glass shade set upon a plate, the glass being prevented from actually touching the plate by some pieces of wood that support it, so that fresh air may get in under the edge of the glass to replace some of the burnt air.

If this experiment be conducted in a cold room, water will be deposited on the sides of the glass and run down into the plate.

If you think over it, you will acknowledge this to be an unexpected and most interesting fact, namely, that water is formed when a flame is burning, especially when you consider that in order to put out a fire water is thrown over it; but nevertheless it is a truth, and you have seen how it may be demonstrated or shown to be so.

The extraction from chalk of the elements that compose it is called *decomposing* the chalk; and on the other hand, when water is formed by the two gases, the two gases are said to *combine* to form water.

It is the especial province of Chemistry to consider the combinations of elementary bodies that form the various substances of which the world is composed, and the decompositions of compound bodies. It is really a science full of interest, which will increase as your knowledge of the subject increases. Chemistry tells what part of the air is essential to life, how it is continually becoming a part of our bodies, and how some part of our bodies is all the while turning into gas, and passing off all around.

Chemistry teaches us why fires burn brightly, what it is that makes bread rise, and how the bread nourishes our bodies; how soaps are made, why they cleanse clothes and other things, and also how paints and dyes are mixed and employed.

Many common things become most deeply interesting when they are looked at with the aid of Chemical Science. A most distinguished chemist (the late Michael Faraday) delivered six lectures to a young audience in London on the "Chemical History of a Candle," and they have been published, making a book of more than two hundred pages.

In this book experiments are described, many of which you will be able to repeat for yourselves with bottles and tubes that cost very little money, and by exercising a little contrivance you can try many of them with what is already at your own homes.

But you need not do even this to be interested in Chemistry, because there are things that illustrate the subject continually happening before you. There are experiments, so to say, going on not only around, but within you; and you have only to look and chemical action will be noticed everywhere about you.

CHAPTER II.

HYDROGEN.

In the last chapter you were told that water was composed of two gases. One of these bodies has received its name from this circumstance, and is called Hydrogen, a word which means "water-maker." The other is called Oxygen, a word which signifies "acid-maker," because those who first discovered it thought that those bodies which are called acids, of which you will learn more presently, necessarily contained oxygen as one of their component parts.

Hydrogen is the lightest of all known substances. A bulk of air weighs more than fourteen times as much as an equal bulk of hydrogen; while gold, which is one of the heaviest substances known, is nearly two hundred and thirty thousand times as heavy as hydrogen.

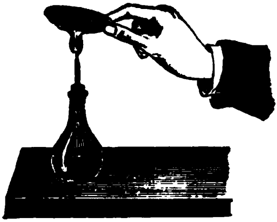
A balloon will rise into the air when the weight of the gas inside, added to that of the bag and of the car with its contents, is less than the weight of air which would occupy the space taken up by them altogether; so that hydrogen is a very good substance for filling balloons and makes them rise very swiftly into the air.

Hydrogen is a colourless gas, like the air we breathe. There are many other gases, which, like hydrogen and air, are colourless and transparent, that is, can be seen through like clear glass. The gas we burn is different from either hydrogen or air, although it contains hydrogen in combination with other substances. Oil or tallow is changed into gas before it burns, the flame being burning gas. When wood or coal is burnt, all except the ashes that are left passes into the air, and generally manifests itself by a flame.

Hydrogen burns in air with a faint flame, giving little light, but very great heat, and in doing so forms water by combining with oxygen, which is in the air.

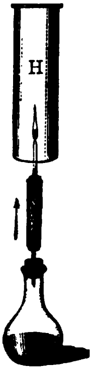
When hydrogen is burned in oxygen water is formed by the combination of the hydrogen with the oxygen. Not an atom of either is lost, the atoms merely go into a new condition, uniting to form a liquid. In doing this, the bulk of both is made much smaller; what we call steam or vapour is first formed, and as this cools, dew appears in little drops; these drops collect together, and then water, as we usually see it, begins to gather.

Fig. 3.



There are many ways in which you can see that water is formed by the burning of hydrogen in air. One is represented in Fig. 3. This figure you have seen before in the first chapter, page 2, and the experiment was then partly explained; you are now prepared to understand a further explanation. Hydrogen and a body called carbon are combined in tallow or gas. It is remarkable that this lightest of all gases helps to form solid substances. As melted tallow goes up the wick, air brings oxygen to it all around, and heat makes this oxygen unite with both carbon and hydrogen in the tallow or gas. If under a jar, inverted as the jar or receiver marked H is, in Fig. 4, a lighted candle be placed, then by the union of oxygen with the carbon a gas is formed, which being colourless and transparent, you cannot see although it is really in the jar. Uniting with the hydrogen, oxygen forms water, which also goes up in vapour with the other gas, and so also you are unable to see it. But the inside of the glass being cool, the vapour soon collects upon it, and makes it dim, until after

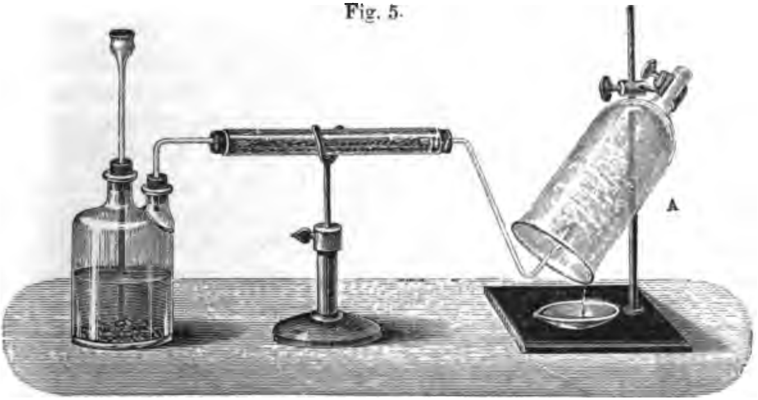
Fig. 4.



a little time there is enough water to form drops which trickle down.

In Fig. 5 you have an experiment, in which hydrogen is burned alone without carbon. The materials for making hydrogen are contained in the bottle which you see, and the gas as it forms passes out along the tube, in which is placed a substance for drying the gas before it reaches the jet where it is burned. The vapour, formed by the union of the hydrogen with the oxygen of the air, is condensed on the sides of the receiver A, and runs down on to the plate.

Fig. 5.

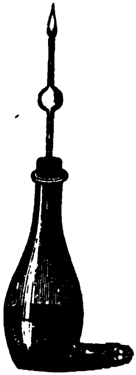


If you take a piece of polished metal, such as a spoon or knife blade, and hold it for a few seconds over a candle or small gas flame, it will be dimmed by the vapour formed, as you have been told on page 2. Where many gas-lights are burning inside a room, water formed in this manner trickles down the window-panes. If H, in Fig. 4, be considered as a room, then water caused by the flame will soon form on the glass.

It is now time for you to learn how hydrogen may be obtained. Sulphuric acid is a body containing hydrogen in combination with sulphur and oxygen, and if this body be brought in contact with zinc, a *reaction,* as chemists call it, occurs.

The zinc takes the place of the hydrogen, forming a new compound, sulphate of zinc, and the hydrogen of the acid is set free. Into a bottle or retort, therefore, we place some pieces of zinc, some water, and some sulphuric acid, and into the neck we put a cork with a glass tube in it. The gas bubbles up through the liquid, carrying the air that is in the vessel along with it, and soon, when all the air is driven out, escapes alone, and can be lighted, just as ordinary gas issuing from a gas-burner. The water is introduced partly in order to moderate the violence of the action, by diluting the acid, so that it may be more gradually brought in contact with the zinc. In Fig. 6 is represented this apparatus, which is often called the "philosopher's candle." In making the gas in this way, great caution is required not to hold a light to the tube before all the air is driven out, for a mixture of hydrogen with common air explodes like gunpowder, and there is danger of the bottle being broken in pieces.

Fig. 6.

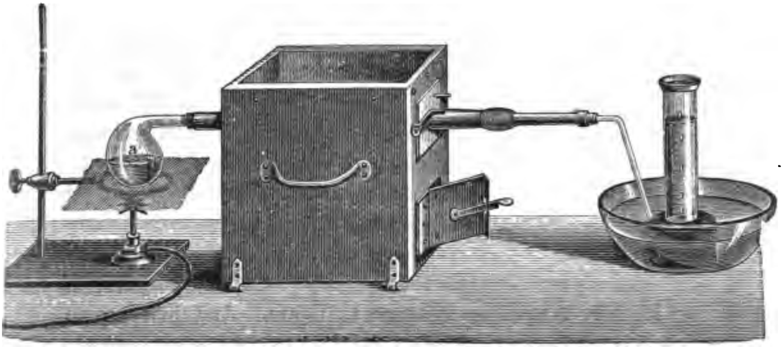


The flame of hydrogen is of a very pale blue colour; giving out so little light that in bright daylight you may not be able to see it at all, but possessing great heating power, as may be shown by introducing into the flame a piece of fine wire, which will very soon become red hot; you may hence infer that there may be great heat where there is very little light.

Another way of producing hydrogen depends on the rapidity with which oxygen, the other component of water, combines with iron. The apparatus is represented in Fig. 7.

You see a furnace with an iron pipe like a gunbarrel running through it. Into this pipe are put fine scrapings of iron or bits of needles. At one end is another pipe from a retort containing water, and the water is heated by a gas flame or spirit lamp. At the other end is a tube with its open end under some water in a large basin or trough. As the water boils, steam, which is only water in a finely divided state, passes through the iron pipe in the furnace. As it passes among the bits of iron, the oxygen of the water, in consequence of the heat, combines

Fig. 7.



with the iron, forming an oxide of iron or rust. In doing so it parts company with the hydrogen, which, therefore, goes on alone through the other end of the pipe, and bubbles up through the water. There is over the end of the pipe a glass vessel called a *receiver*—a wide-mouthed bottle with its open end downwards answers very well. This receiver is filled with water by being completely immersed in the large basin, and then turned mouth downwards and partly raised out of the water. The mouth of the receiver is then placed over the end of the pipe, and the bubbles of gas, being lighter than water, rise up and take the place of the water, until the receiver is quite full of hydrogen gas.

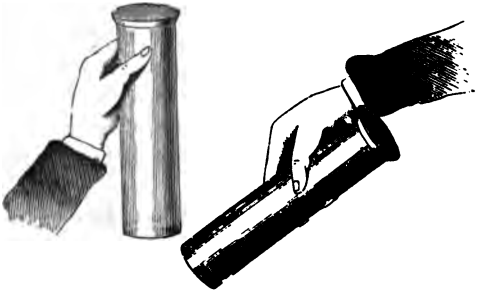
The basin is called a *pneumatic trough.* It contains a shelf, a little under the water, on which receivers may stand; and sometimes the shelf has an opening in it, so that the gas may be discharged through it into a receiver placed over the hole, to save the trouble of holding the receiver in the hand over the end of the discharge pipe.

A jar of gas is easily taken from the vessel when wanted for experiment. Your own ingenuity may contrive several ways. One is to slip a small plate or piece of window-glass under the mouth of the jar before it is removed. It may then be taken from the trough of water, and placed on a table for examination.

If the receiver be placed mouth upwards on a table and the glass plate removed, the gas will instantly rise into the air, since hydrogen is so much lighter than air; for the same reason, if the receiver be held mouth downwards, its contents will not escape for some time even though the plate be taken away.

If the receiver, held mouth downward, is gradually turned upright, the hydrogen will pour from it in an *upward* stream, exactly in the same way as water would pour in a *downward* stream from a vessel held in the contrary position, the hydrogen being lighter, the water heavier, than air. And just as we catch the downpouring water in another receiver placed *mouth-upward*, so we catch the upstreaming hydrogen in a receiver placed *mouth-downward*. Fig. 8 represents this, which is often called the *upward decantation* of hydrogen.

Fig. 8



If a light be applied to the receiver, it will be seen that hydrogen burns differently, according to the way in which the jar is held. If held with the mouth upwards, the gas, rapidly rising as it burns, bursts with a large flame, as seen in Fig. 9, and under some circumstances attended with a sharp report. But, if held with the mouth downward, the gas burns very quietly, as seen in Fig. 10, and at the same time the light, if pushed up into the jar, is itself extinguished. The gas does not come out freely, because, being lighter than air, it tends upwards and not downwards. As hydrogen is so light, it has a very curious effect upon sounds, making them dull and weak. If what is called the squeaking toy is made to utter its voice in a jar of hydrogen the sound will be faint; and if hydrogen is breathed into the lungs the voice becomes weak, hollow, and unearthly. By placing a glass tube over a jet of burning hydrogen, as represented in Fig. 11, musical sounds can be produced, which vary with the length and size of the tube. An amusing variety of sounds can be produced by using different tubes, and raising or lowering them while the flame is singing.

Fig. 9.

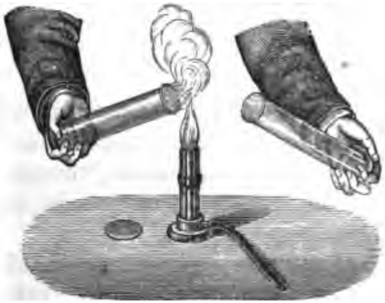


Fig. 10.

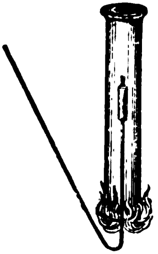
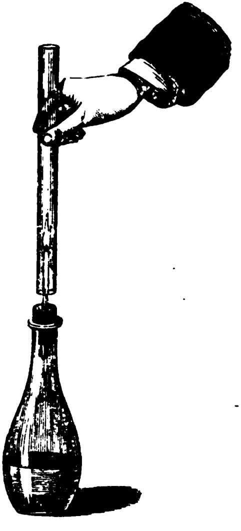


Fig. 11.



CHAPTER III.

OXYGEN.

We now come to speak about the other component of water besides hydrogen, namely Oxygen, a substance whose name you were told in the last chapter means "acid-maker," though, as you will learn further on, there are a great many acids which do not contain oxygen at all.

This gas oxygen is one of the most important substances to the life of man of all those found on the earth's surface. Indeed, you could not have done without it at any moment since you were born. Every time you breathe, some of it is taken into the lungs, and if the air did not contain oxygen, you would die just as quickly as you would under water.

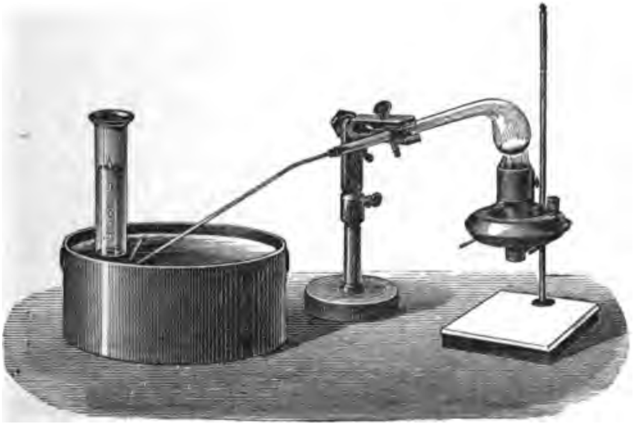
Oxygen is nourishment to the body. Though it does not, like other food, go into the stomach, it passes into the lungs, and is quite as necessary to the support of life as the food we swallow; in one sense it is more so, for we may live for days without food being put into the stomach, but lung-food must be taken in every minute. Absorbed by the lungs, oxygen is a most important constituent of the blood that runs in the arteries and veins, and assists in making the solid parts of the body—bones, muscles, skin, &c.

Besides the important part which it plays in the sustenance of animal life, oxygen forms a considerable portion of the world around us. As you know, water consists in a very great measure of oxygen, and the ground beneath our feet and even solid rocks are formed partly of this substance.

It may seem strange that gas can make part of such solids as flesh and bone; but in winter a liquid becomes a solid, when water freezes into ice; and this same water is always present in the atmosphere as a gas, although, being so thin and transparent, it can no more be seen than the other gases in the air. Water then exists in the three states of a solid, a liquid, and a gas; and oxygen too in the bones is a solid, in the blood and in water is a liquid, and in the air is a gas.

Oxygen gas can be separated from some of the substances with which it is united, and so be obtained by itself. Chemists commonly use for this purpose a crystalline substance called chlorate of potassium, a name which you will better understand when you have read more of this book. This substance is reduced to a state of powder, and mixed with dioxide of manganese, a black powder which also contains oxygen; it is then placed in a retort and heated gently, as represented in Fig. 12. Heat causes the oxygen to separate from the crystals, and, passing over through a tube fixed to the mouth of the retort, it can be collected in a receiver placed in a pneumatic trough, just in the same way that hydrogen was collected, in the previous chapter. The receiver may then be removed and the contents examined.

Fig. 12.



First of all we find that oxygen does not burn in air; but if a lighted taper fixed to a piece of wire bent as shown in Fig. 13 is held in a jar of oxygen, as in Fig. 14, it will burn with dazzling brightness, and be rapidly consumed. You will understand the reason for this when you remember what you were told in the last chapter about a burning candle or taper. It is the oxygen of the air that makes the taper burn at all, so you see that the more oxygen the taper gets the brighter and the faster it burns. Now only about one fifth of the air is oxygen, and so the taper in the jar will burn about five times as brightly and as fast as in common air.

Fig. 13.

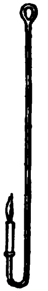
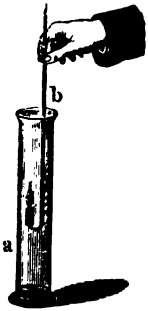


Fig. 14.



Some substances which do not burn brightly or with flame in common air may become bright and flaming in oxygen gas. Charcoal, burning in an ordinary fireplace, appears of a dull red heat, with no life in it—neither sparks nor flame; but if a piece of this dull charcoal be put into oxygen, it will have a supply of gas five times as abundant as before, and consequently the activity of the combustion is increased; this is manifested by the great number of bright sparks thrown all around and by the rapid consumption of the piece of charcoal.

There is no substance that makes so brilliant a light when burning in oxygen as phosphorus, which sends out a very thick white smoke most brilliantly illuminated.

If sulphur be burned in oxygen gas, the smoke has a most beautiful blue colour, and arranges itself in a very singular way, going up straight in the middle of the jar, and then falling in curious rings down the sides. The gas which is formed by the combination of sulphur with oxygen in this combustion is called sulphurous anhydride.

The mode in which you may arrange a taper, or charcoal, or phosphorus, or sulphur for burning in oxygen, is shown in Figs. 15 and 16. A glass jar is first filled with oxygen in the way shown in Fig. 12, page 13, and the substance to be burned is placed at the end of a wire which is held up by being passed through a piece of card, as seen in Fig. 16; or a bell glass may be placed over the substance as in Fig. 15.

Fig. 15.

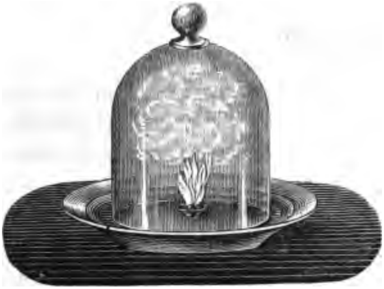
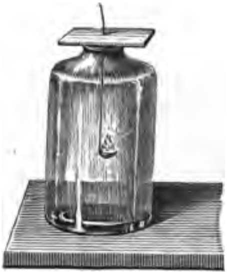
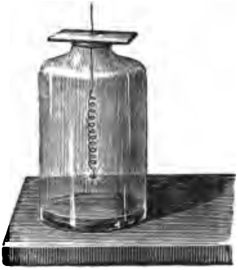


Fig. 16.



There are some substances which most people think cannot burn at all, yet they do burn very readily in pure oxygen. Iron is one of these. If you take a piece of fine iron or steel wire, and twist it as you see in Fig. 17, a splendid fire can be made with it in oxygen. As you cannot set it on fire in air, and then introduce it into the oxygen as is done with phosphorus, sulphur, &c., you must dip the end of the wire in sulphur, or fasten to it a piece of charcoal, or something that will burn in common air, and light that. If it is then introduced into the oxygen, the burning substance on the end of the wire sets fire to the wire itself, which if it be of steel sends out showers of sparks in all directions. The sparks are due to the presence of carbon in steel (see page 97), but if the wire be made of pure iron, it will burn away with a quiet glow.

Fig. 17.



CHAPTER IV.

NITROGEN.

BESIDES oxygen, the chief constituent of common air is a gas called Nitrogen, so named because it also forms an essential part of a substance known as nitre; in five gallons of air, about four gallons are nitrogen.

Nitrogen differs from hydrogen and oxygen chiefly in possessing no active properties at all. For instance, nothing will burn in nitrogen, neither will nitrogen burn in air; although it does not act as a direct poison, nitrogen is quite incapable of supporting animal life when breathed. Now you will remember that hydrogen burns in air; oxygen, although it does not burn, supports the combustion of other bodies, and is essential to animal life as lung-food; so you see then that nitrogen is distinguished easily from them, by possessing none of those properties.

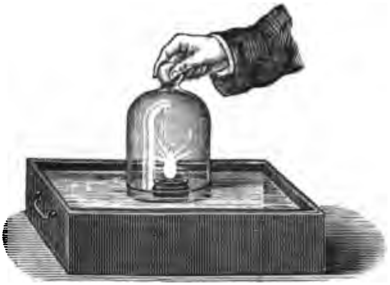
Although animals cannot live if they breathe only pure nitrogen, yet this gas enters very largely into the composition of the flesh of all of them, and a supply of it in a proper form is necessary for the maintenance of life. It does not enter into the composition of them through the air they breathe, but through the food they eat; nitrogen forming a large part of the vegetable substances that are used for food, thus becoming part of the flesh of animals. In a later chapter you will have an opportunity of learning more on this subject.

Nitrogen does not act as a poison to an animal, for there is going into the lungs of all living creatures four times as much nitrogen as oxygen.

Although, as you now know, nitrogen will not make anything burn nor keep animals alive when it is breathed, nevertheless the presence of this gas in the atmosphere is most useful, both for the proper regulation of burning fires, and for the due supply of oxygen to the lungs. Nitrogen *dilutes* the air, and renders the action of the oxygen less energetic, just in the same way that water added to wine or spirits renders them less strong as drinks. You remember how brightly bodies burn in pure oxygen, and so you may understand that were it not for the presence of nitrogen, our fires would burn too fast, and not only the coal, but the iron of the grates would burn, and our houses too, in many instances; and in the same way our lungs would get oxygen a great deal too fast, and we should be constantly as hot as we are after violent exercise. We should have the greatest difficulty in keeping ourselves cool; we should be troubled much more by inflammation and fever, and thus our lives would be much shorter than they are at present. So you see, nitrogen is not without its use, inactive and dull though it be.

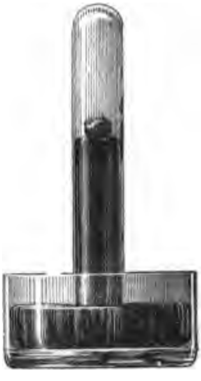
Though nitrogen by itself has no active properties, yet in combination it helps very often to form powerful and energetic bodies. For instance, nitric acid, hartshorn, and prussic acid, each contains nitrogen, and is a body which has very strong properties, and is a violent poison. You can get nitrogen from the air by a very pretty experiment, which consists in getting rid of the oxygen by making it combine with another body, and dissolving the product in water.

Fig. 18.



A little place is hollowed out on a flat piece of cork and some chalk sprinkled into it; into the hollow is put a piece of phosphorus, and the cork is floated in a basin or trough of water (Fig. 18). The phosphorus is lighted, by touching it with a hot wire, and a good-sized glass jar is inverted over it so that the edge of the jar touches the water. If the jar holds a pint, a piece of phosphorus about the size of a pea will be needed. Great caution is required in handling the phosphorus, as it takes fire very easily. Watch the experiment, and you will notice that the phosphorus burns more and more dimly, and at last dies out before it is all consumed, and at the same time the water rises in the jar; the dense white fumes at first formed gradually disappear as they are dissolved by the water. The explanation of all this is, that the phosphorus in burning unites with the oxygen, and continues burning as long as there is any oxygen left with which to combine; it then goes out; the white smoke formed is a body known as phosphoric anhydride, which dissolving in the water, forms phosphoric acid; and nitrogen only is left in the jar.

Fig. 19.



If you wish to know exactly how much oxygen can be taken away from the air, you must modify the experiment in the following way. Instead of using a water trough, you must use a basin containing quicksilver, or, as it is generally called, mercury, and instead of the glass jar, use a test tube. Then, instead of burning phosphorus, make a pellet of tow and soak it in a solution of pyrogallate of potassium, and cover it with the test tube. All the oxygen will be gradually absorbed by the pellet, and the mercury will rise in the tube, as in Fig. 19, and you can then measure more accurately the proportion of nitrogen left after the experiment is over.

CHAPTER V.

CARBON.

THUS far we have been studying some of the properties of the gases which constitute water and air, namely, hydrogen, oxygen, and nitrogen; now we come to the consideration of another element which is not a gas, but a solid. Carbon, however, forms gaseous combinations with each of the former bodies, and, therefore, may be said sometimes to exist as a gas. It ought to be of the greatest possible interest to us, as it is one of the principal sources of the wealth and importance of our English nation.

Carbon, in a state of more or less purity, appears in various forms all over the world. It is found nearly pure in the diamond, in plumbago or graphite or, as it is more often called, blacklead (a very improper name, by the way, for there is not a particle of lead in it), and in anthracite coal; and it forms the principal part of all the coal that is burnt. Besides, it can be artificially extracted in the forms of wood charcoal, coke, lampblack or soot, and ivory-black or animal charcoal.

It may seem strange and improbable that the diamond, the most valuable and brilliant of gems, should be the same in its composition as a piece of common black charcoal, and as no one has yet been able to make a diamond it is right you should understand why the chemist considers them to be the same thing. The reason is simple, and is as follows. When a diamond is burnt in a jar of oxygen gas it forms identically the same compound as a piece of charcoal does when it burns in oxygen, namely carbonic anhydride gas; and if two substances both form the same compound, chemically speaking they are the same thing.

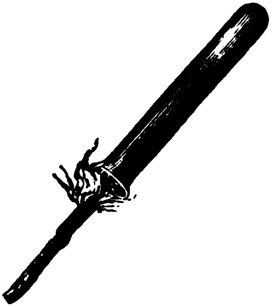
The diamond is perhaps the hardest substance in the world; that is, you cannot scratch a diamond with anything else; so that in preparing a diamond to be "set," that is, fixed as jewels are in brooches, it has to be ground with diamond powder. A glazier utilises this property of diamonds in using a crystal of diamond to cut glass.

All the different forms of carbon can be burned, most of them in common air; but *plumbago* and the *diamond* require pure oxygen to effect their combustion.

Ordinary charcoal is made from wood. Wood consists substantially of carbon and of oxygen and hydrogen in proportion to form water, so that if we can drive off the oxygen and hydrogen in the form of water, the carbon will be left behind. This may be done by putting the wood into an iron retort and heating it in a furnace, when the oxygen and hydrogen are driven off, chiefly in the form of water, and carbon is left behind, retaining the form of the wood from which it was made. This is however generally effected by a much rougher process. A heap of wood is formed, and covered with turf, in which openings are made at the top and bottom to admit a small amount of air. The wood is then set on fire, and some of it slowly burns. The heat from the burning wood is used to drive off the oxygen and hydrogen from the rest of the logs, care being taken that sufficient oxygen is not supplied to cause the whole mass of wood to burn. As the amount of wood consumed depends upon the supply of oxygen, the quantity of air admitted through the holes in the turf is a matter of some importance; if the supply is not properly regulated, either the mass is insufficiently charred, or too much wood is burnt and so there is a waste of material. Of course that part of the wood which does the work of charring the remainder does not form charcoal itself, because its carbon unites with the oxygen of the air in burning, and goes off as carbonic anhydride gas.

You can readily make charcoal in a small way yourself. If you take a test tube, Fig. 20, and hold a slip of burning wood in it, the tube prevents the air from getting freely to the wood, so causing a smothered burning, and thus a slender piece of charcoal is produced.

Fig. 20.



Coal, like wood, consists almost entirely of carbon, oxygen, and hydrogen; it is indeed supposed to have been originally wood, and to have been gradually changed in composition and appearance by the prolonged action of moisture, great heat, and pressure. But this is a matter of some uncertainty, as we have never been able artificially to produce coal from wood, nor actually to trace its formation by nature from the vegetable to the mineral condition.

Soot, another form of carbon, is formed in the chimney when the supply of air to the coal or wood is not sufficient to consume its carbon entirely, that is, to convert it all into carbonic anhydride. The heat from that portion of the coal which *is* burning is sufficient to drive off the oxygen and hydrogen which in combination with carbon are contained in the rest of the coal, but not to heat them sufficiently to make them burn, or in other words combine with oxygen. The gases as they pass off carry with them minute particles of carbon from the coal, and these lodge on the sides of the chimney and are called soot. When fires are properly regulated, so that the right proportion of oxygen and carbon meet in the grate, there is no smoke, and such fires are said "to consume their own smoke." This is a subject of interest to those who use very large quantities of coal, such as ironfounders and manufacturers in general; as the quantity of carbon which may go away and be wasted in smoke, in such furnaces as they use, may be very considerable in the course of a year; and it may all be saved and utilised by a proper attention to the construction and stoking of their furnaces. Unfortunately this subject does not meet with the consideration it deserves, and vast quantities of fuel are every day wasted and lost by the carelessness or ignorance of those who use it.

Lampblack, so much used in painting, is a kind of charcoal. It is made by letting the smoke of burning resin or pitch into a chamber lined with leather, when the lampblack collects on the sides of the chamber.

There is a large quantity of carbon in many of the things which we see about us. There is carbon in chalk and in marble. So too there is carbon in shells of all kinds—eggshells, oystershells, &c.; it exists in wood, in leaves, in flowers, in fruit, and indeed in most vegetable substances; and the bodies of all animals have carbon as one of their principal ingredients. It does not show itself as carbon in these things, any more than hydrogen appears as hydrogen gas in water. It is, as it were, hidden by being chemically combined with other bodies; but by separating it from these, it can be brought from its concealment and shown as carbon.

CHAPTER VII.

CARBONIC ANHYDRIDE.

CARBONIC anhydride, as you learned in the previous chapter, is a gas composed of *carbon* and *oxygen;* and here we have another example of a solid body forming a gas when in combination.

Its name, carbonic *anhydride*, signifies that it belongs to the class of oxides which unite with water to form acids; but carbonic acid, the particular acid formed in this case, is a body which up to the present time has never been obtained pure; it is always mixed with more or less water, and any attempt to take the water entirely away results in the decomposition of the acid again into water and carbonic anhydride.

Carbonic acid forms with metals or their oxides a series of compounds called "carbonates;" what these bodies are you shall learn more particularly in another chapter. Chalk and marble are carbonates of *calcium;* potash is a carbonate of *potassium*, soda is a carbonate of *sodium;* and there are many other bodies of the same class, some of which, like marble, are found among natural products of the earth, others, like soda, are the results of some process of manufacture. When carbonates are brought in contact with other acids, carbonic acid is formed, which, unless there is a very large quantity of water present, becomes immediately decomposed into water and carbonic anhydride, the latter coming off as gas. One of the methods used for preparing carbonic anhydride is to make *hydrochloric acid* act upon *marble.* If some pieces of marble are put at the bottom of a glass vessel and a little hydrochloric acid poured upon them, an effervescence occurs, caused by the gas being set free from the been discovered which consists only of oxygen, nitrógen, and carbon.

In the next place we shall find that more than one combination belongs to each class. For instance, there is more than one combination of hydrogen with oxygen alone, more than one of hydrogen with carbon alone, two of oxygen with carbon alone, and so on. These differ in the proportion by weight of the bodies which form them, a proportion, however, which is always the same for any particular substance. For example, as we shall presently see, there are two oxides of carbon; one of them always contains 42·86 per cent. of carbon, the other 27·27 per cent., and this percentage never varies, however the bodies may be obtained.

In this chapter we will consider only those compounds which consist of oxygen and one of the other bodies, those, namely, which correspond to the first, fourth, and sixth columns in the diagram. Such bodies are termed in general *oxides.*

There are two oxides of hydrogen, but one only is of sufficient importance to be worth our attention. This oxide, commonly known as water, and formed, as you ought to remember, by the burning of hydrogen or of bodies containing hydrogen in oxygen or air, contains 88·89 per cent. by weight of oxygen, the remainder of course being hydrogen, or by volume, in the proportion of two volumes of hydrogen to one of oxygen. To consider adequately the properties of this most beautiful and wonderful substance would require a large book, so that we must content ourselves with a mere glance at some of the most important or interesting points about it, remembering, at the same time, what a very slight knowledge we are acquiring in comparison with the importance of the subject.

Briefly, then, water exists in three states—solid, liquid, and gas; when solid it is called ice, when a gas it is often called steam. Water forms seven-eighths of the entire human body, and exists in all living tissues, whether animal or vegetable. It is always present in more or less quantity in the atmosphere as an invisible gas; even on the clearest day, when the air appears dry, there is water-gas in it. As the amount which can be present depends upon temperature, by lowering the temperature of the atmosphere sufficiently, its presence can always be demonstrated, the excess of water being then deposited as dew, as, for instance, by bringing a very cold tumbler into a warm room.

Steam occupies nearly seventeen hundred times the bulk of the water from which it is formed.

It was shown in chapter ii. how hydrogen can be obtained from water when in the form of steam, by the action of iron upon the oxygen; but there are certain metals, potassium and sodium, which will effect the same thing at the ordinary temperature of water. This will be again referred to in the chapter which treats more particularly of those metals.

Water is chiefly useful to the chemist from its power of *dissolving* solid substances, that is, rendering them liquid and transparent and mixing uniformly with them; as, for instance, when sugar or salt is put into water. The *solution*, as it is called, differs from a *chemical compound* in many important particulars. Firstly, when a chemical compound is formed there is always an evolution of heat, but when a substance is dissolved in water the mixture is colder than before. This may be readily illustrated by a very simple experiment: sulphuric acid when added to water *combines* with it; Glauber's salt, on the contrary, *dissolves* in it. So if two tumblers or beakers of water are taken and a thermometer placed in each, and a little sulphuric acid be poured into one, while some Glauber's salt is thrown into the other, the thermometer will rise in the former beaker, and sink in the latter. In adding sulphuric acid to water be careful to pour it in very gradually, or the heat produced will crack the glass. In the second place, a chemical compound consists always of definite proportions of its constituents, while in a solution the ingredients may be present in any proportion whatever.

By referring to the diagram above you will see that the sixth line indicates a set of compounds of oxygen with nitrogen. These are five in number, and contain respectively 36·36, 53·33, 63·15, 69·56, and 74·07 per centage of oxygen, or if we take such portions of each as contain the same weight of nitrogen, the weights of oxygen in each will be in the proportion of the numbers 1, 2, 3, 4, and 5.

The names and proportions of these different compounds may be tabulated thus:

				Nitrogen.		Oxygen.	Percentage of Oxygen.
In 22	lb. of	Nitrous oxide,	there are	14	lb. and	8 lb.	36·36
30	„	Nitric oxide	„	14	„	16 „	53·33
38	„	Nitrous anhydride	„	14	„	24 „	63·15
46	„	Nitric per-oxide	„	14	„	32 „	69·56
54	„	Nitric anhydride	„	14	„	40 „	74·07

Notice that the first, second, and fourth compounds are called simply "oxides," but the third and fifth receive a different name, one which you have heard before, namely, "anhydride." They too are really oxides like the others, but they have this other name also for the following reason. They belong to a peculiar class of oxides which, when they come in contact with water, *combine* with it to form acids, while the other oxides merely *dissolve* in water without uniting chemically with it. Nitrous anhydride unites with water to form nitrous acid; nitric anhydride with water forms nitric acid. Observe, too, the use of the terminations *ous* and *ic* to denote different proportions of oxygen in the compounds. We shall come to speak more about these anhydrides when we are learning about acids. (See also p. 108.)

Nitrous oxide, more commonly known as "laughing-gas," resembles oxygen in supporting combustion very brilliantly, but it is readily distinguished from it by being much more easily dissolved in water. It can be breathed, but it has, under certain circumstances, a very peculiar effect upon the system of a person breathing it. If mixed with air it produces a state of exhilaration and excitement, which gives it the name "laughing-gas;" but, if breathed pure, it causes a drowsiness and insensibility to pain for a short time, during which teeth may be taken out and surgical operations performed without the patient being conscious of anything which goes on. Of the other four compounds of oxygen with nitrogen the two next in order are gases, the third a liquid, and the fourth a solid, at the ordinary temperature of the air.

In the fourth column of the diagram are indicated the oxides of carbon. These are two in number, one of which only will be mentioned in this chapter; the other being of sufficient importance to deserve a chapter all to itself. They are carbonic oxide and carbonic anhydride, and the proportion of oxygen in each is shown below.

	Carbon.	Oxygen.	Percentage of Oxygen.
In 7 lb. of Carbonic oxide, there are	3 lb. and	4 lb.	57·14
11 „ Carbonic anhydride „	3 „	8 „	72·72

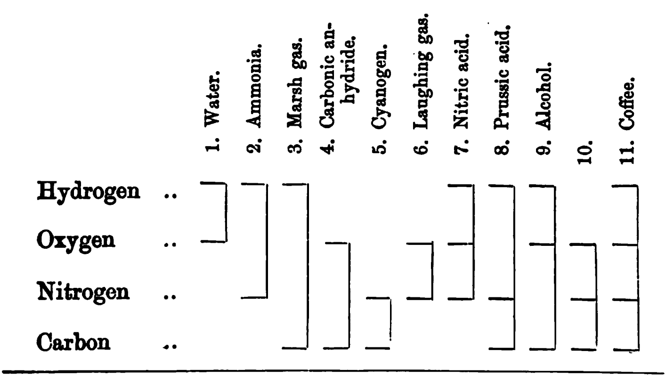
Thus there is twice as much oxygen to a given amount of carbon in the one as in the other. A gallon of carbonic anhydride contains a gallon of oxygen, while a gallon of carbonic oxide contains only half a gallon of oxygen.

Carbonic oxide is a colourless gas which burns with a beautiful pale blue flame, often to be recognised in a fire burning in a common grate. It may be formed in many ways, but the particular method most interesting to us is that in which it is formed by passing carbonic anhydride over red hot carbon. This process goes on constantly in stoves and furnaces, and is one of the sources of the waste of fuel, because in this way a quantity of carbon is carried off unburnt without being converted into carbonic anhydride, as should be the case if it were properly consumed. Carbonic anhydride is formed at the bottom of the furnace where the air can get at the coals, and passes up through the red hot fuel higher in the furnace; there being no supply of air at this place, everything coming from below, the carbonic anhydride takes up some of the carbon as it goes along, and becoming carbonic oxide, passes off unburnt. If, however, it should get oxygen before leaving the furnace, it burns, and the whole of the fuel is thus utilised.

CHAPTER VI.

OXIDES—ANHYDRIDES.

We have considered the properties and the method of obtaining four elementary bodies, namely, hydrogen, oxygen, nitrogen, and carbon, and it will now be time to study some of the combinations which they form with one another. We shall find first that, leaving out of consideration the *proportions* of each element in the different compounds, they form ten sets, in which occur every possible combination of the four elements, taken two, three, and four together, with the exception of one. The following diagram will illustrate this; the brackets show which elements are united together in each set, and at the top of each bracket is placed the name of some body which serves as an example for the class to which it belongs in this arrangement.

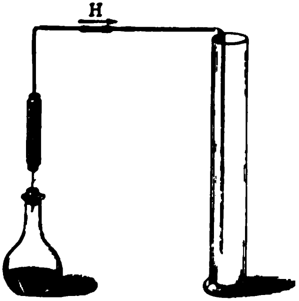


Here you will notice that the last bracket but one has no name above it; the reason is that hitherto no compound has marble, and the vessel becomes full of carbonic anhydride, the air having been pushed out of the vessel by the gas as it rose.

Carbonic anhydride is formed when charcoal is burnt in oxygen gas (as represented in Fig. 16), or in common air. In the latter case the carbonic anhydride is mixed with nitrogen, which does not combine, like oxygen, with burning carbon, and therefore is unchanged by the combustion. The amount of nitrogen present in the mixture can easily be calculated, if you remember that five gallons of air contain four gallons of nitrogen.

For most of the experiments that we want to try with carbonic anhydride, it answers very well to obtain the gas in the way that was first described in this chapter; but for some experiments it will not do to have anything left in the bottom of the jar. In that case the gas must be made in a retort or a flask, and so pass out and be collected in jars, in the same manner that we obtain oxygen gas. Or, we can obtain it in the way represented in Fig. 21. Here is a flask containing marble and hydrochloric acid; one end of a bent tube passes through the cork, the other end nearly touches the bottom of the jar in which the gas is to be collected. The gas formed in the flask drives out the air before it, and, being heavier than air, remains in the bottom of the receiver after issuing from the mouth of the delivery tube. The thick part of the tube just above the flask contains materials for drying the gas as it passes over, a process which you will understand better at a future day. The properties of the gas in the receiver can now be examined. It has no colour and is transparent, in these respects resembling hydrogen, oxygen, and nitrogen; but it has a faint smell, and a slightly acid taste.

Fig. 21.



It does not support combustion, and will extinguish a lighted candle lowered into the jar. This property of carbonic anhydride may be made the subject of a pretty experiment. Two jars may be taken, one full of oxygen, the other full of carbonic anhydride. A candle lowered into the jar of carbonic anhydride goes out. If now it be instantly put into the other jar before the spark on the wick is extinguished, the oxygen re-lights the candle into a bright flame, and thus the candle can be put out and rekindled several times in succession.

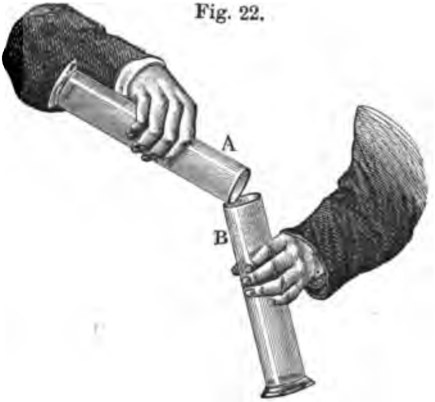
The candle goes out in carbonic anhydride for lack of oxygen to make it burn. You may think this a singular thing, because there *is* oxygen in carbonic anhydride; in fact, a gallon of carbonic anhydride contains as much oxygen as a gallon of oxygen itself, and therefore five times as much oxygen as a gallon of air, which you know will support the combustion of a candle. But the difference between the two cases consists in the fact that in carbonic anhydride the oxygen is *chemically combined* with the carbon, and does not separate from it to unite with the combustible gases of the candle, and in air the oxygen is simply *mixed* with the nitrogen. This is a very good illustration of a striking difference between the two classes of bodies—chemical compounds and mechanical mixtures.

With respect to this property of not supporting combustion, carbonic anhydride resembles hydrogen and nitrogen, but differs from oxygen.

It also resembles nitrogen in another respect, namely, that it will not support animal life; but with this difference between them, that while an animal breathing nitrogen dies for want of oxygen, carbonic anhydride acts as a direct poison, a very small proportion of it in the air which is breathed being sufficient to destroy life.

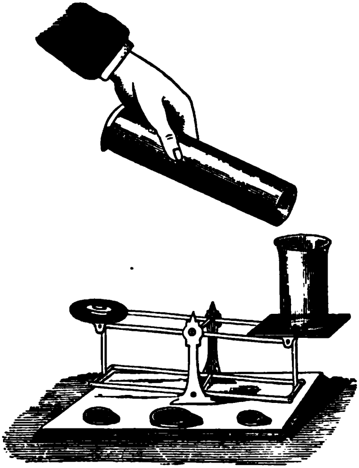
Carbonic anhydride is much heavier than air, a gallon of the gas weighing more than half as much again as a gallon of air. You can therefore pour it, in the same way, and for an exactly similar reason, as you pour water from one vessel into another. Of course the vessel into which you pour it is full of air; but the air rises and overflows when the heavy gas enters, just as oil would if you poured water into a vessel filled with oil.

Fig. 22.



Suppose you were to place a lighted candle or taper in the jar B, in Fig 22, and you pour carbonic anhydride from the jar A, as you see represented there; the gas passes down into B, forcing up the air, and when it reaches as high as the flame, the light will be extinguished.

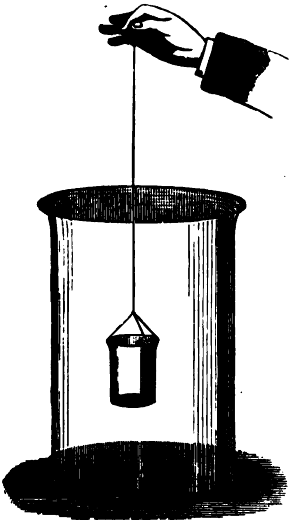
Fig. 23.



In Fig. 23 is represented a very pretty experiment, showing that this gas is heavier than air. First balance a jar with a weight. Now the jar is full of something, namely, air, and that air has weight; so that we in reality balance a jar *full of air*. If carbonic anhydride is poured, as represented, into the jar on the scales, the jar will descend and the weight rise, because there is now a gas in the jar heavier than the air which filled it originally.

A jar filled with this gas can be emptied with a little bucket (Fig. 24), just as a tank of water might be emptied, and air will take the place of the gas which is removed.

Fig. 24.



If a soap bubble fall into a jar of carbonic anhydride it will not sink to the bottom, as it would if the jar were full of air, but descend a little way, and then ascend and remain in its open mouth. This is because the air that is blown into the bubble is lighter than the gas in the jar, and the bubble therefore floats on the gas as a boat on water. If the jar be only half full of the gas, air therefore filling the upper half, the bubble will stop half way down.

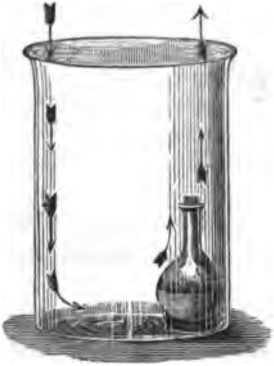
Another very entertaining experiment, showing that carbonic anhydride is heavier than air, is to pour the gas upon four or five lighted candles placed in a row, when one after another of them will be put out.

This gas is sometimes used to put out fire, and an apparatus has been devised called "*L'Extincteur*, or chemical fire engine," which consists of a reservoir small enough to be carried on the back, containing the gas stored up under great pressure, to which a hose with a stopcock is attached. By opening the stopcock the gas rushes out in a stream, which can be directed upon the flames to be extinguished. Some years ago a coal mine in Scotland was on fire, and could not be extinguished by any ordinary means, and there was danger that a large quantity of coal would be wasted, if the fire continued; a Mr. Gurney then made a quantity of carbonic anhydride in a part of the mine where it would sink down to the fire, and so put it out

Sometimes carbonic anhydride is produced in wells, and, being so much heavier than air, it remains at the bottom. If a man goes down into such a well, he will have no difficulty at first, because the air is good; but when he is near the bottom, where the gas has accumulated, he will gasp for breath and fall; and if anyone, not understanding the cause of his trouble, goes down to assist him, he too will fall senseless, and both will quickly die. The way to ascertain whether carbonic anhydride has accumulated at the bottom of a well is to let a light down into it. If it goes out, or even burns very dimly, there is enough of the gas to make the descent perilous. A man going down a well should always take a candle with him, which he should hold a considerable distance below his mouth. If the light burns dimly, he should at once stop, before his mouth gets any lower and he takes some of the gas into his lungs.

When this gas is in a well or pit, of course it must be expelled before a man can descend. There are several expedients for doing this. One is to let a bucket down frequently, turning it upside down, away from the mouth of the well, every time it is brought up, a plan which will remind you of the experiment represented in Fig. 24.

Fig. 25.



But a better way is to let down a bundle of burning straw or shavings, so as to heat the gas. Now heated bodies expand, gases very much more than solids or liquids, and, in expanding, the weight of a certain volume, say of a gallon, becomes lessened. So that if we can heat the carbonic anhydride enough to make a gallon of it weigh less than a gallon of air, it will rise out of the well just as hydrogen gas would do. Fig. 25 shows how you may perform this experiment upon a small scale.

A flask, full of hot water, and corked, is placed on a pad inside a deep beaker full of carbonic anhydride. If it stands on one side of the beaker, the effect on the gas inside will be that indicated in the illustration. The flask heats the gas all round it, and makes it expand until it is lighter than the cold air above; consequently there is an upward current on that side of the jar, while cool fresh air pours in a downward current on the other side. The two currents follow the direction of the arrows. That the gas has passed away can be shown by lowering a lighted taper, which will in that case burn as brightly as when outside.

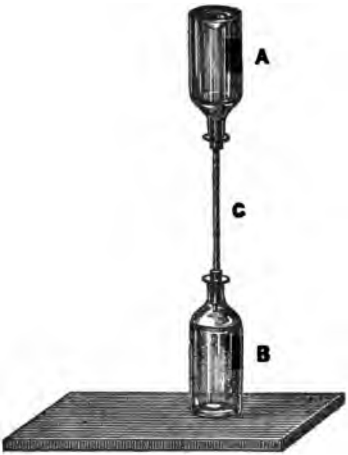
Another expedient is to throw lime mixed with water down the sides of the well. Lime is the product of the action of water upon oxide of calcium. The anhydride, as soon as it comes in contact with the water, forms carbonic acid, and the acid, acting on the lime, forms carbonate of calcium or chalk, which adheres to the stones, as the mixture drips down the sides.

There are places where carbonic anhydride collects in large quantities; one of these in Italy is called the *Grotto del Cane*, or Dog's Grotto. On the floor of this grotto or cave there is always a layer of carbonic anhydride high enough to reach above the head of a dog, but not above the head of a man. A man living near shows the grotto to visitors, taking a dog in with him, which of course falls down insensible. He however quickly brings him into the fresh air again, and with a dash of cold water revives him. The dog falls down not merely for want of oxygen, but because the gas does him positive harm.

The gas in this cave comes from crevices in the rocks, a not uncommon occurrence in other places, especially in the neighbourhood of volcanoes, where it is also seen sometimes bubbling through the water of springs. It remains in the grotto for the same reason that it remains in wells and in glass receivers, because the air is very still, and it is kept from the wind which would blow it about and cause it to mingle more quickly with the atmosphere.

You must not suppose that carbonic anhydride would always remain in the bottom of an open receiver, unless fresh gas is added as it is in the Grotto del Cane. Some of the gas is always leaving the surface and mingling slowly with the air, a process which is called *diffusion*, and which takes place when any gas is exposed to the air but protected from draught. Fig. 26 shows an experiment which illustrates the diffusion of gases.

Fig. 26.



Two jars, A and B, of equal size are filled, the one, A, with hydrogen, which is a very light gas, and the other, B, with carbonic anhydride, which is a very heavy gas, and they are connected by a glass tube, C, as shown in the figure, so that one jar communicates with the other, the hydrogen jar being placed uppermost. At first sight we should expect each gas to remain where it is for an indefinite time, the light gas being at the top, the heavy carbonic anhydride being at the bottom. But if we leave the jars in position for a day or two, and then examine their contents, we shall find that half the hydrogen has descended into the bottom jar, and that its place is taken by half the carbonic anhydride of the lower jar, so that there is an equal quantity of hydrogen and of carbonic anhydride in each jar. We may ascertain that this is the case by breaking the connection between the jars and immersing each of them mouth downward in a solution of caustic potash in water; all the carbonic anhydride will be absorbed, and the water will rise up half way into each jar, leaving only the hydrogen, which may be recognised by its inflammable character.

The burning of charcoal in a close room is injurious to health; even death may be occasioned by the union of the carben in the charcoal with oxygen in the air. Hence charcoal ought never to be burned except in the open air, or in a room in which doors and windows are open, or in fireplaces where the chimney supplies an outlet by which the carbonic anhydride can escape. You see too that if any one be poisoned by gas from burning charcoal, the remedy is to open doors and windows and let fresh air enter the room. Remember that the doors must be opened as well as the windows, for air must come along the floor to drive out the gas.

The foam that comes from bottled beer, porter, champagne, &c., when the cork is drawn, is caused by carbonic anhydride, which is held imprisoned in the liquid by the pressure of air and gas inside as long as the cork is tight. Water can be made to dissolve more of the gas under pressure, and when this pressure is taken away, the gas comes off. In soda-water the gas is forced into the liquid by a pump, and the bottle is corked under pressure; when the cork is removed the gas is liberated and bubbles up. Very often in what is called soda-water there is no soda at all; it is simply a solution of carbonic anhydride in water; but properly this ought not to be the case. Very often soda-water is made from two white powders dissolved in water. One of these is carbonate of sodium, the other is tartaric acid. When they come together in a state of solution the tartaric acid takes the sodium and sets free carbonic acid, which is immediately decomposed into water and carbonic anhydride, the anhydride being given off and causing effervescence. When we drink soda-water, we take some of this gas into the stomach; but poisonous as it is when it enters the lungs, it not only does no harm in the stomach, but is refreshing, and in moderate quantities may do good.

CHAPTER VIII.

AMMONIA, CYANOGEN, MARSH GAS, OLEFIANT GAS.

In former chapters we have examined the properties of those bodies which are indicated in the first, fourth, and sixth columns of the diagram in chapter v.; we shall now proceed to study some of the bodies indicated in columns 2, 3, and 5, those, namely, which are composed of two elements only, neither of which is oxygen. The first of these is the gas called Ammonia, its name being derived from the fact that the salt from which it was originally obtained was found near the temple of Jupiter Ammon, in Lybia. It is a combination of hydrogen with nitrogen in such proportions that two gallons of it, when decomposed, furnish a gallon of nitrogen and three gallons of hydrogen; so that in two gallons of the compound ammonia we have *four gallons* of gas *condensed to two.*

This gas is colourless and transparent, but has an acrid taste and a most pungent smell, causing tears to stream from the eyes.

It does not support the combustion of a candle, but will itself burn in hot air or in pure oxygen. Like carbonic anhydride, it is fatal to animal life, but when much diluted it acts as a stimulant, the properties of sal volatile and of smelling-salts being due to the ammonia which is given off from them. Ammonia may be distinguished from any of the gases before mentioned by its smell, and by the extreme readiness with which it is dissolved in water, one gallon of cold water taking up more than a thousand gallons of the gas, but giving off again a considerable quantity when heated. Another distinguishing property of ammonia, which however is common to the class of bodies called alkalies, of which ammonia is a member, is its action on certain vegetable colouring matter. Turmeric is a yellow vegetable dye, whose colour is turned to a reddish brown when it is exposed to ammonia.

Litmus is a blue substance obtained from one of the plants called lichens, some of which you may have seen growing on old walls and ruins, and its colour is turned red by the action of acids; the blue colour may however be restored by ammonia or any other alkali.

Ammonia is obtained from sal ammoniac, the salt mentioned above, by heating it with quicklime, that is, oxide of calcium. The gas, however, cannot be collected over the pneumatic trough which contains water, because it is, as you have been already told, so extremely soluble in water; but, being lighter than air, it can be collected in a receiver placed mouth downwards, just as it would be placed for holding hydrogen; or, if you are anxious not to have the least trace of air mixed with it, a trough must be used containing mercury, a body which has no action on ammonia, the receiver prepared for it being also filled with mercury and inverted over the trough.

Ammonia is formed when organic matter, that is, matter which forms organised beings, animals and vegetables, putrefies or decays, and is also one of the chief products when such bodies are cremated or burnt. The pungency of the smell of burnt feathers or hair arises from the ammonia which is formed from them by the heat.

Cyanogen, the body which is signified in the sixth column of the diagram, is a colourless transparent gas, with an odour of peach kernels, and poisonous to breathe; it burns in air with a peculiar purple-tinged flame, and is dissolved by water to a certain extent. A gallon of water dissolves four gallons of the gas. It is chiefly interesting to the chemist, as being the first compound body which was found to combine with elementary bodies in the same way that elementary bodies combine with one another, and its discovery by Gay-Lussac, a French chemist, at the beginning of this century, was the starting point of a most important change in the theory of chemical actions, which has exercised a gradually increasing influence from that time to this. You will not at present be able to appreciate its importance or to understand the chemical theory alluded to, but at some future day, when you are more familiar with chemical actions, you will doubtless share the interest it has awakened in the minds of experienced and learned men.

The third column is now the only one left which signifies the union of two of the elements only. The body selected as a specimen, marsh gas, consists of carbon and hydrogen, and, as its name implies, is formed in marshy places and stagnant pools, where vegetable matter is decaying. It is best made by heating a salt called acetate of sodium with hydrate of sodium, or, as it is often called, caustic soda, in a retort. Caustic soda will eat away glass if it is heated with it; so, to prevent the retort from becoming worn through, some quicklime is put in, which cakes round the glass and prevents the action of the caustic soda upon it. The gas which comes off may be collected in the usual manner over the pneumatic trough, and its properties can then be examined.

Marsh gas is transparent and colourless, and a gallon of it weighs rather more than half as much as a gallon of air. It is not dissolved by water; and does not support the combustion of a candle, but itself burns in air with a bright yellow flame, which, however, by arranging that the gas shall be partly mixed with air before it is burnt, may be made nearly colourless and transparent. When marsh gas is burnt, both the carbon and the hydrogen in it burn, that is, unite with oxygen in the air; the former becoming carbonic anhydride, the latter forming water. If a gallon of marsh gas be mixed with two gallons of pure oxygen, and a light is applied to them, they explode, much in the same way that hydrogen and oxygen do, and both marsh gas and oxygen disappear entirely; one gallon only of gas being left, which will be found to be carbonic anhydride; the water formed at the same time becoming condensed immediately to the liquid state, and consequently occupying an altogether inappreciable volume. From this we may learn how much hydrogen there is in a gallon of marsh gas, if we bear in mind certain other facts which we have already met with. We may reason as follows.

The result of the combustion of a gallon of marsh gas with two gallons of oxygen is one gallon of carbonic anhydride gas together with an unknown quantity of water. On page 27 we learnt that a gallon of carbonic anhydride contains a gallon of oxygen; consequently, as we originally started with two gallons of oxygen, the remaining gallon of oxygen must have gone to form the water. But on page 30 we see that a gallon of oxygen, in order to form water, must unite with two gallons of hydrogen, therefore there must have been two gallons of hydrogen in the gallon of marsh gas from which the water was made. You may find this rather hard to follow at first, but it is well worth an effort to master, and you will better see its significance when we return to the subject in another chapter.

Marsh gas is the chief constituent of the gas we burn, which is made by heating coal in iron retorts. In coal mines this gas frequently bursts out from a crevice, discharging itself in jets sometimes for months together, and is one of the sources of danger to which the miner is exposed; a mixture of it with air causing explosions in the mine, which too often are attended with loss of life. As the mines are dark the workmen are obliged to carry lights with them, and when a flame comes in contact with a mixture of marsh gas (or, as miners call it, firedamp) and air, the gas is set on fire, and the bearer of the lamp is killed either by the explosion which follows, or by the carbonic anhydride which results from the explosion. George Stephenson the engineer, and Sir Humphry Davy soon after him, invented a lamp which may be safely carried into such a mixture without causing an explosion, depending upon the fact that a flame will not pass through very fine tubes or wire gauze. Figure 27 represents the lamp designed by the latter,

Fig. 27.

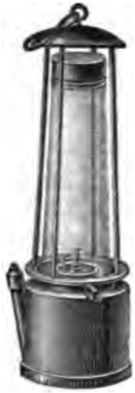


Fig. 28.

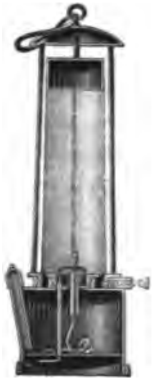


Fig. 29.

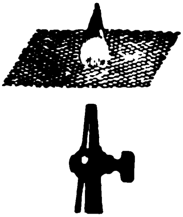
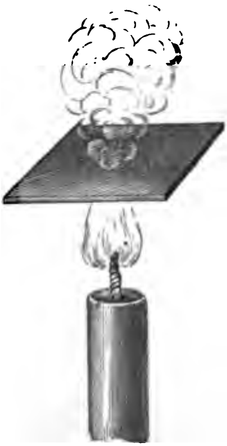


Fig. 28 showing its internal arrangements; this lamp is the one generally used, and is called the "Davy safety lamp."

That a flame will not pass through such a lamp you can ascertain for yourself by making the experiment in Fig. 29. Hold a piece of wire-gauze over a jet of gas issuing from a burner, and apply a lighted taper above the gauze. The gas will burn above, but will not descend to the jet: or press a piece of gauze down on a burning candle, as shown in Fig. 30, when the flame will bend down underneath, and though smoke may come through no flame will appear on the upper surface.

The explanation of this is, that for a flame to be kindled, the gas must be first raised to a certain temperature; and this

Fig. 30.



the gauze prevents, because, being a good conductor of heat, it carries away the heat of the flame on one side of it, before it can raise the temperature of the gas immediately in contact with it on the other side sufficiently to commence chemical action.

Besides marsh gas there is another constituent of coal gas which resembles marsh gas in several ways. It too is a compound of hydrogen and carbon, but the proportions in which they are combined are different in this case, as may be inferred from the following fact. A gallon of olefiant gas, for this is the name of the body, requires three gallons of oxygen to consume it completely, the result of the combustion being two gallons of carbonic anhydride and some condensed water. As in the case of marsh gas, we reason thus: two gallons of carbonic anhydride contain two gallons of oxygen, consequently the remaining gallon of oxygen must have gone to form the water; one gallon of oxygen combines with two gallons of hydrogen to form water, therefore a gallon of olefiant gas contains two gallons of hydrogen. Thus we see that a gallon of marsh gas and a gallon of olefiant gas contain the same quantity of hydrogen; but we shall find the quantity of carbon to be different when we remember that a gallon of marsh gas furnished carbon enough for only one gallon of carbonic anhydride, while a gallon of olefiant gas has sufficient carbon in it to form twice that quantity; that is, olefiant gas has twice as much carbon in it as marsh gas.

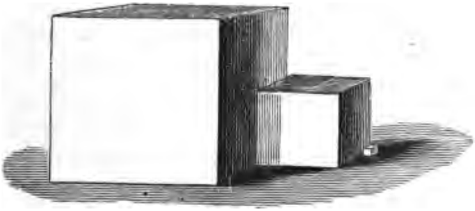
CHAPTER IX.

THE AIR.

You have already learnt incidentally a good deal about the air, but in this chapter we will supplement that knowledge with some more facts about its composition and properties.

The principal components of air are oxygen and nitrogen; but there are generally some other gases present, and of these carbonic anhydride is the most important and the most constant. The relative proportions of these three gases may be understood roughly by examining Fig. 31, in which the large cube represents the bulk of nitrogen, the next the bulk of oxygen, and the very little cube at the side the bulk of carbonic anhydride in the air. The atmosphere is considered to be from forty to fifty miles high, and consequently exerts an enormous pressure on the surface of the earth, which has been estimated at more than forty-two thousand tons on every acre, of which seven tons are due to carbonic anhydride. There is also in the air a very variable amount of water gas, and slight traces of ammonia, nitric acid, marsh gas, and sulphuretted hydrogen, a

Fig. 31.



body with which we have not yet become acquainted, but which together with ammonia is formed by decomposing matter.

Continual additions are made to the carbonic anhydride in the air in various ways. Every fire, for instance, adds to it; for, as you have read in previous chapters, when wood, coal, and other substances burn, the carbon in them unites with the oxygen of the air forming carbonic anhydride.

A fire, then, lessens the oxygen, and at the same time adds to the carbonic anhydride, as may be exemplified by placing a lighted candle under a glass jar on a plate, when the flame gradually becomes dim, and at length goes out. If, as the candle is about to go out, the jar is raised, the flame will brighten again, because in so doing carbonic anhydride, which, being heavy, has fallen to the bottom of the jar, is let out, and fresh air enters to supply oxygen. As the carbonic anhydride collects at the bottom, if you put a long and a short candle under the same jar, the short one will be extinguished first.

Every animal, too, is breathing out carbonic anhydride, a fact which can be proved by a very simple experiment. Put some lime water into a glass, and breathe into it through a tube. After a little time the water becomes milky, owing to the formation of chalk (carbonate of calcium) by the combination of the carbonic anhydride with the water and the lime. This will remind you of one of the methods described for removing carbonic anhydride from a well, in chapter vii.

The quantity of carbonic anhydride breathed out in a day is very considerable; it is calculated that a full grown man breathes out in twenty-four hours more than two pounds of the gas, and in this there is not less than half a pound of solid carbon. He throws off from his lungs therefore, in the course of a year, nearly two hundred pounds of charcoal, considerably more than his weight.

The air, then, after it is breathed, is altered in two ways, both of which make it less fit to be breathed again; the oxygen is diminished, and carbonic anhydride is added to it; the amount of nitrogen is unaltered, for it is neither taken up by the lungs nor given off by them.

The way in which air is rendered poisonous by being breathed may be exemplified by the story of a ship called the *Londonderry*. The vessel was crowded with emigrants, and during the voyage met with a severe storm. All the passengers were ordered to keep in the cabin; the only fresh air they could get came through an opening in the deck, and consequently the air down below became very foul and oppressive; but the miseries of the crowded people became intensified when, in consequence of the waves breaking over the ship and pouring down into the cabin through the opening, the captain ordered the hatchway to be nailed over with a tarpaulin, that is a cloth which is water-and-air-tight. Then no pure air whatever reached them, and every breath expired added carbonic anhydride to the atmosphere of the cabin. For some time their sufferings were unknown to those on deck, as the noise of the storm drowned their cries of distress; but at length one of the emigrants succeeded in forcing a hole in the tarpaulin, through which he attracted the attention of the captain and made him acquainted with the state of things below deck. The tarpaulin was at once removed, when it was found that some had already died, and many were in a dying state from the want of air. However, the fresh air which came in on the removal of the tarpaulin revived most of them, just as the frosh air let into the jar in the last experiment brightened the expiring flame of the candle.

Another notable instance may be cited, in which the Viceroy of Bengal, Surajah Dowlah, after having taken Calcutta, in June, 1756, thrust one hundred and forty-six English people into a loathsome dungeon, known as the Black Hole, where in one night, there not being fresh air enough for them to breathe, the greater part of them died of suffocation.

The air, being thus continually charged with carbonic anhydride in the ways above mentioned, would in time become unfit for the support of animal life, were there no means of counteracting this tendency supplied by nature in other ways. This work is done by the leaves of plants, which perform a function analogous in kind, but opposite in effect, to the lungs of animals. Trees and plants breathe, but in so doing they absorb carbonic anhydride, and give out in exchange oxygen, and thus the balance of proportions in the atmosphere is preserved. Leaves present on their surfaces minute pores or mouths of tubes, which, under the influence of sunlight, absorb carbonic anhydride, whence it is carried to all parts of the plant, the oxygen being separated eventually from the carbon and re-discharged, while the carbon is retained and furnishes material for the growth of the tree, carbon being, as you know (see chapter v.), one of the chief ingredients of wood.

You would probably expect, then, to find the proportion of carbonic anhydride in the air to be very different in the neighbourhood of a large forest, and in a place where there are very few trees, and that also there would be a greater quantity of carbonic anhydride in winter, when the trees are destitute of leaves, than in summer when they are covered with foliage. But this is not the case, owing to the tendency, alluded to in the last chapter but one, of gases to mix together until they are in the same proportions throughout their whole substance, a tendency which is very much assisted in the case of the gases in the atmosphere by the winds which are constantly moving different portions of the air from one part of the earth to another.

The amount, however, of water-gas present in the air, you were told, varies very much at different times, and the cause of this variation, although not belonging properly to the chemical branch of science, is so interesting and important, that the following attempt to give a brief though necessarily imperfect explanation of it will be well worth your attention. We all know practically that boiling water is hot, and that the steam which is formed is hot also; if there is water in the air, it must be necessarily of the same temperature as the rest of the atmosphere, and consequently it must be quite different in respect of temperature from the water-gas which is formed from boiling water.

Now whenever water has one of its surfaces exposed, that is to say, not pressing against a solid, as for example the upper surface of water in a bottle half full, or the surface of a sea or lake or pond or puddle, some of it will be turned into a gas at that surface, and pass away from the rest (a process called *evaporation*) until the gas which is formed exerts a certain definite pressure on the surface of the water, the amount of which depends upon the *temperature of the gas*, being greater if the gas has a higher, smaller if the gas has a lower temperature. When this pressure is reached there is a sort of balance between the pressure of the evaporated gas on the one hand and the tendency of the water to evaporate on the other, the amount of force, as it were, on each side being regulated by the temperature of the evaporated water-gas. In the case of the atmosphere this pressure is due to the *weight* of gas above the surface of water exposed, and therefore may be taken as a measure of the amount of water-gas present in a given volume of the atmosphere. Suppose, then, on a hot day the surface of water in any particular place has been giving off a quantity of gas until the pressure has reached the point where evaporation stops (a point, remember, which depends on the temperature of the water-gas which is formed), and then by some means the gas is cooled, as for instance by meeting with colder air; the pressure becomes too great for its temperature, and must therefore diminish. That is, some of the water-gas must become liquid water again, and consequently change the amount of water in the atmosphere. In such a way as this dew is formed, which really is water-gas condensed during the night, which had been evaporated during the previous warmer day, but which, as the temperature falls, has become in excess of that which is required to stop evaporation.

The effect of the oxygen and nitrogen in the air upon the evaporation of water is not to alter in the least degree the amount of water evaporated, but only to diminish the *rate* of evaporation. If there were no gases in the air at all, the only difference would be that the water would *instantly* throw off enough gas to balance its tendency to evaporation, whereas as the case now stands some time is required for this point to be reached. The weight of the *air* then pressing on the water has no other effect upon its evaporation, except that its rate is checked.

CHAPTER X.

CHLORINE — BLEACHING.

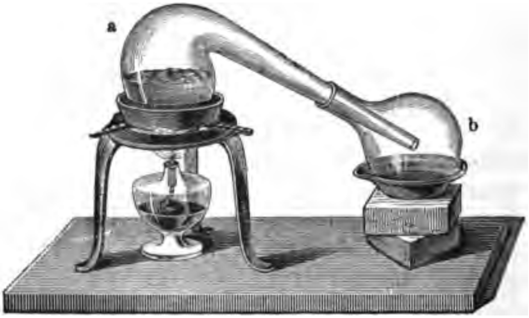
COMMON dinner-salt is a substance made up of two elements, one of which is a metal called sodium, and the other a body of which we shall now consider the properties. It is called chlorine, a name derived from a Greek word signifying yellowish-green, because of the peculiar colour which this body possesses.

Chlorine combines with many other elements besides sodium, and the compounds which it forms with single elements are called chlorides, just as compounds of oxygen with single elements are called oxides. Thus common salt is called by chemists chloride of sodium; calomel is called chloride of mercury. Chlorine may be obtained from common salt by mixing the salt with some dioxide of manganese (the body used in the preparation of oxygen), placing the mixture in a retort with some sulphuric acid and water, and applying a gentle heat.

Chlorine is a gas, at the ordinary temperature of the air, of a yellowish-green colour, and so excessively irritating to the lungs when breathed that the greatest caution must be exercised in its preparation not to let any of it escape. This is rather a difficult matter, because, as chlorine is dissolved by cold water, the pneumatic trough cannot be used for collecting it; neither is the mercury trough available, which was used for collecting ammonia, as chlorine acts very readily upon mercury.

The gas is about two and a half times as heavy as air, and can therefore be collected, like carbonic anhydride, by the displacement of air. Fig. 32 shews an apparatus which may be used for this purpose, in which *a* is the retort in which the gas is made, and *b* is a receiver, placed on a lower level, to collect the gas as it comes over.

Fig. 32.

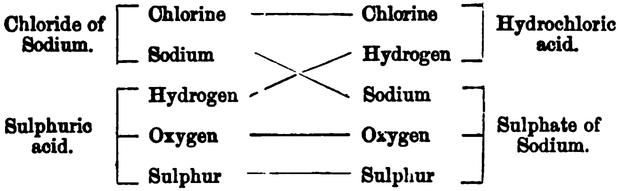


If it is essential to obtain the gas for any experiment free from admixture of air, chlorine may be collected over the pneumatic trough in which hot water is used; for water dissolves more of the gas at low than at high temperatures. When a jar of the gas is done with, care must be taken not to let the gas escape into the air of the room in which the experiments are being performed; the best plan is to pour into the jar some hydrate of sodium (caustic soda) and shake it up well until all the smell of the gas is gone.

Chlorine has a great tendency to combine with hydrogen, forming a compound known as hydrochloric acid, or, as it is sometimes called, muriatic acid, a name given to it for reasons which will be explained in the chapter on acids; in so doing a gallon of chlorine combines with a gallon of hydrogen, forming two gallons of the acid, which is also a gas like hydrogen. In consequence of this tendency chlorine will support the combustion of a candle, or of bodies containing hydrogen, but as the carbon of the candle does not burn in chlorine, the flame will give off great quantities of smoke or soot. If a piece of blotting paper be soaked in turpentine, and placed in a bottle of chlorine, the action of the gas on the hydrogen of the turpentine is so energetic as to cause the paper to catch fire, and at the same time great quantities of soot are deposited. A mixture of chlorine and hydrogen may be caused to combine by applying a flame to it, or by subjecting it to the action of light. If the direct rays of the sun fall upon the mixture the combination takes place with explosive violence, but by exposing it to diffused daylight the action goes on quietly and gradually. We have learned that chlorine dissolves in water, but this solution is difficult to keep for any length of time, as, if placed in the daylight, the chlorine will separate the hydrogen from the water, setting free the oxygen, and soon the solution becomes one of hydrochloric acid instead of chlorine. Many other elementary bodies have a strong affinity for chlorine, especially if they are in a finely divided state. For instance, copper foil, powdered antimony, and arsenic will take fire spontaneously in chlorine, as will also be the case with phosphorus, each of them forming a chloride of the element which undergoes combustion.

Hydrochloric acid is a gas, colourless and transparent, fuming when it comes in contact with the air, in consequence of condensing its moisture, and forming with it a liquid compound which has not the same tendency to evaporate or pass into a gas that pure water has. It is very soluble in water, but not so much so as ammonia, a gallon of water dissolving about 480 gallons of hydrochloric acid gas. It does not, however, act upon mercury, and so can be collected over the mercury trough.

This gas can be formed for examination by acting upon common salt with sulphuric acid, when the hydrogen is supplied by the acid, the chlorine by the salt, and the sodium which is left from the salt uniting with the sulphur and oxygen which remains from the acid forms a new salt commonly known as Glauber's salt, but which chemists call sulphate of sodium. The following diagram will render this reaction more easy to be understood and remembered:



Here we see that there is an interchange of sodium and hydrogen between the two bodies, which is an example of what chemists call *reactions*.

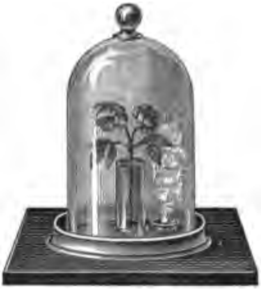
From hydrochloric acid chlorine can be obtained by the action upon it of dioxide of manganese, under the influence of a gentle heat.

The tendency of chlorine to form hydrochloric acid, whenever it comes in contact with a body containing hydrogen, makes the gas useful to us in two most important ways. By its means we can bleach vegetable colouring matter, and we can also destroy many deleterious gases, which are compounds of hydrogen.

For bleaching goods the chlorine is prepared by acting with an acid, usually sulphuric acid, on bleaching-powder, a body which contains chlorine and parts with it readily. The chlorine which is set free combines with the hydrogen of the dye, and at the same time forms a colourless compound with the other ingredients of the colouring matter, and in this way effects a bleaching action. Another way in which chlorine bleaches is by setting free oxygen from water, when it combines with the hydrogen. Oxygen, when it is first set free from a combination, acts much more powerfully than under other circumstances, and in this case forms colourless compounds with the materials it bleaches. So that in this case chlorine only bleaches indirectly, the actual work of whitening the material being performed by oxygen.

Woollen goods, that is, goods made of the hair of animals, are not bleached by chlorine, but only goods made of some material of vegetable origin. A piece of coloured calico placed in a jar of chlorine gas will be unbleached as long as it is dry; but if the rag be moistened the colours will be extracted. A good experiment to show the bleaching effect of chlorine is to put a little bleaching powder and acid into a saucer, and some flowers in a pot close to it; cover both flower-pot and saucer with a bell-glass, when the flowers will soon become quite white.

Fig. 33.



Chlorine will bleach ink spots, but will have no effect upon printer's ink.

Chlorine is used very extensively in the manufacture of paper, the colour of the rags from which the paper is made being removed by the action of this gas.

Chlorine is also of great use in purifying foul air, for which purpose it is made by placing moistened bleaching-powder or chloride of lime in saucers. The acid necessary to set free the gas is supplied by the combination of the carbonic anhydride of the atmosphere with the moisture of the saucer.

Salt, the principal source of chlorine, is found native in all parts of the world, the most famous mines being those of Poland, Hungary, and Cheshire. Though salt has been taken from the salt mines of Cracow for centuries, it is supposed there is still enough to supply the world for centuries more. Some parts of these mines have been shaped into beautiful forms as the salt has been taken out; chapels, halls, &c., have been made, the roofs of which are supported by huge pillars of salt, which present a very splendid appearance when illuminated by torches and lamps.

In England most of our salt is obtained from salt-springs, the most noted of which are in Cheshire. When the name of a place ends in *wich*, as North*wich*, Droit*wich*, &c., salt either has been or is now found there. In the water of these springs there is between eight and nine times as much salt as there is in sea-water. To get salt from them wells are dug, and the brine is pumped up and conducted to boilers where the water is driven off by heat. Sometimes, however, the salt is obtained by a slower process; the brine is exposed to the sun in extensive shallow vats, called evaporating pans, and the water gradually passes off into the air, leaving the salt behind. In hot climates salt is often obtained from sea-water by this method.

CHAPTER XI.

IODINE—BROMINE.

THERE are in sea-water, besides chlorine, two other substances very much resembling chlorine in several ways. One of these, iodine, is found there combined with sodium just as chlorine is, but the quantity of it is much smaller than the quantity of chlorine in the sea, so small indeed that it would almost escape observation, were it not for the fact that sea-weeds extract it from the water and store it up in their tissues. Sea-weed is to us the source of iodine; the weed is burnt, and the ashes that are left, called *kelp*, contain a certain quantity of iodide of sodium, from which the element iodine may be obtained by a process which is rather complicated, but which is in the main similar to that by which chlorine is extracted from chloride of sodium.

Iodine, whose name is derived from the Greek word for its colour when a gas, is a dark coloured solid somewhat resembling blacklead, which passes into a gas having a splendid violet tint when gently heated. This vapour is one of the heaviest gases known, and will support the combustion of a taper, much as chlorine does, and resembles chlorine also in setting fire to phosphorus spontaneously and combining with it, and in forming a gaseous compound with hydrogen similar to hydrochloric acid, which consequently is called hydriodic acid. Iodine has such a strong tendency to combine with phosphorus that they will unite if they come together even in the solid state, the chemical action causing sufficient heat to ignite the phosphorus.

Iodine is most useful in medicine, though poisonous if taken in more than very small quantities, and it also forms with silver a compound which is acted upon by light in a peculiar way, so that photographic pictures may be taken by its agency.

Bromine is extracted from sea-water, a gallon of which contains rather less than a grain of bromine, by a process something like that for the extraction of iodine from kelp. It is not, however, combined with sodium in sea-water, but with another metal named magnesium, a metal which is found in considerable quantities, combined with other substances, all over the world, and which is remarkable for its singular property of burning in air, producing as it does so a light of most extraordinary brilliancy. Bromine is found almost invariably wherever common salt is deposited, and also in salt springs.

Bromine is a brownish-red liquid giving off deep orange-red fumes, which have such an exceedingly offensive smell as to give the substance a name derived from the Greek word signifying stench. It is a very deadly poison, and more irritating to breathe in vapour than even chlorine. It forms with hydrogen, like chlorine and iodine, a gaseous combination which is called hydrobromic acid.

These three substances, chlorine, iodine, and bromine, are peculiar to sea-water, in which they are always found combined with other substances. These compounds, together with various other salts found in sea-water, originally came from rocks and soil washed by the sea, or rivers which run into the sea, and consequently the proportion of the different matters dissolved is subject to a slight variation in different parts of the world, depending partly upon the nature of the soil which prevails in any particular place. The names of the different substances found dissolved in the sea are chloride of sodium, chloride of potassium, chloride of magnesium, bromide of magnesium, sulphate of magnesium or Epsom salts, sulphate of calcium or gypsum, carbonate of calcium or chalk; of which chloride of sodium exists in by far the largest quantity, the second place being occupied by the chloride and sulphate of magnesium. Some inland seas and lakes contain more saline matter than the ocean itself, partly because they have no outlet, partly because there is so much salt in their neighbourhood. Such are the Caspian Sea, the Dead Sea, and the Lake Aral.

The more salt there is dissolved in water the more dense it is, that is, the heavier a cubic foot of the water becomes. The effect of this increase of density is to increase the buoyancy or floating power of the water, as may be illustrated by the following experiment. An egg will sink to the bottom of a jar full of fresh water; but if some strong brine, that is, a mixture of salt and water, is poured down a long tube to the bottom of the jar, it will force up the pure water and egg, the egg remaining at the bottom of the fresh water, but floating on the surface of the brine.

In consequence of this it is that the Dead Sea has such a floating power, a man having no difficulty whatever in keeping his head above the surface; indeed, so great is the difficulty of keeping one's limbs and body below the surface that swimming is very difficult in this sea. A ship there could carry a cargo which would cause it to sink in river water.

CHAPTER XII.

COMBUSTION.

WHENEVER chemical action takes place heat is either absorbed or given out, the act of combination being attended with a production of heat, and, if it be sufficiently rapid, light also. When a rapid chemical action causes much heat or light, or both, it is called *combustion* or burning. Thus, when oxygen combines with hydrogen to form water great heat is given out, and the hydrogen is said to *burn;* so when iron combines with oxygen in the way mentioned on page 15, the iron is said to *burn* in the gas.

Very often, however, chemical action takes place more slowly, so that no light is produced, as for instance when iron rusts; this is sometimes spoken of as slow combustion. In such cases there is always heat given out, but so slowly and gradually that no light is apparent.

It must not be supposed that oxygen is always essential to combustion. On page 50 it was stated that a candle will burn in chlorine, and it has been shown, too, how chlorine and iodine vapour will support the combustion of many bodies; but in all cases of combustion *in air* it is the oxygen which is the active agent, and so if it is required to preserve any body from combustion in air, it is protected by a covering of some substance which is not acted on by oxygen. For instance, an iron fence is painted to preserve it, because oxygen has no combustive action on paint, and the paint keeps the oxygen of the air from getting at the iron; phosphorus is kept under water for the same reason.

When a fire is put out by smothering, the same cause operates; the oxygen of the air is excluded, and the fire goes out for want of oxygen. An extinguisher on a candle shuts out the air, and a blanket, coat, or rug wrapped round a person whose clothes are set on fire will extinguish the flame by shutting out the air.

When, therefore, fresh fuel, wood or coals, is put on a fire, care must be taken not to smother the fire by putting it on so as to stop the air from getting freely at the burning fuel which is already there, or the fire will be extinguished from lack of the oxygen necessary to keep it burning; and on the other hand, a fire may be kept burning slowly for a long time by so arranging the coals that the air may get at the burning fuel very gradually, a contrivance often made use of by stokers of engines when they wish to moderate the heat of their furnaces, and yet to keep the engine ready for work on a short notice. The action of carbonic anhydride on flame is of the same nature (see page 30).

In order that a body may burn in oxygen it must first be raised to a certain temperature; coal gas, for instance, must be heated by applying a flame to it before it will inflame; but when it has once been ignited, the heat produced by the chemical union is sufficient to keep the gas at the necessary temperature. One way, therefore, of extinguishing a flame is to lower the temperature of the burning substance, and this is the principal way in which water operates in putting out a fire. The water is converted into steam, and so takes a great deal of heat from the fire; it also helps to extinguish the flame by smothering it, the steam which is formed shutting out the oxygen of the air.

It may be considered surprising that water and carbonic anhydride should have this effect, as they are both bodies containing a quantity of oxygen; but the oxygen in them is already chemically united with some substance, and has no tendency to separate and unite with any other. As combustion in air results from the union of oxygen with the burning substance, it follows that the more freely oxygen is brought in contact with the fuel the brighter will be the fire. For this reason bellows cause a fire to burn more fiercely, and often kindle into lively combustion a fire which is nearly expiring. Nevertheless, if too much air is blown into a fire or upon a flame it will put it out, because the air exerts such a cooling action upon the burning bodies as to bring their temperature below that which is necessary for combustion to take place; this is what occurs when a candle is blown out; the flame being extinguished mainly on account of the cooling action of the air forced upon it, but partly also because the burning gases are driven away from their source, so that the fresh gases which come from that source are not kindled.

It has been mentioned already that it is necessary to raise bodies to a certain temperature before combustion can take place (page 59); but this temperature is different for different substances, and sometimes even varies in the case of the same substance according as the combustion is rapid or slow. Thus candle grease, coal gas, and grate fuel require a considerable heat, the heat of another flame, to be applied to them before they will ignite in the air; red-hot iron will burn in pure oxygen; the composition with which a match is tipped will take fire with the small amount of heat which friction gives to it, and iodine and phosphorus, if brought together at the ordinary temperature of the air, inflame spontaneously, although their combustion can be prevented by surrounding them with a mixture of ice and salt, which produces cold enough to bring their temperature below the point at which they can ignite. Phosphorus unites *slowly* with the oxygen of the air at a temperature equal to that of a moderately warm summer's day, but in order that it may inflame and undergo *rapid* combustion it must be raised to a higher temperature, 140° (Fahrenheit).

Some substances cannot burn at all, or at all events they have never yet been raised to the temperature necessary to inflame them. Gold is one of these, which, though exposed to an intensely hot fire, does not combine with oxygen from the air, although it does melt. Gold[1] undergoes neither quick nor slow combustion in air, it does not rust like iron and many other metals; hence, outside work which is covered with *real* gold leaf (not the leaf called Dutch metal, which looks very like gold leaf) never rusts or tarnishes in air.

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[1] A statement has been published with reference to the fire at Chicago, giving results of the various degrees of damage done to ledgers and business books, &c., which were locked up in iron safes. Some of the papers considered best and strongest suffered most, but all the books with *gilt edges* were, when opened, in a perfect state compared to the others; and the question arises, whether it would not be policy to *gild* the edges of business ledgers, &c., &c., of importance.

CHAPTER XIII.

PHOSPHORUS—MATCHES—SPARKS—SULPHUR.

The element phosphorus is found in combination with the metal calcium and with oxygen as phosphate of calcium in the soil of the earth, from which it is extracted by plants and vegetables, and stored up in their seeds, and so becomes a part of the food of animals.

Of the body of animals it forms a most important constituent, phosphate of calcium being the substance to which bones chiefly owe their hardness. When bones are burnt, the ash that is left consists mainly of phosphate of calcium, from which the element phosphorus may be extracted by a suitable process.

Phosphorus is a soft yellow solid with much the appearance of wax, and is easily melted. As, however, phosphorus undergoes slow combustion in warm air, and is rapidly burned at a very slightly elevated temperature, it must always be melted either under water or in an atmosphere of gas which has no free oxygen in it, such as hydrogen, nitrogen, or carbonic anhydride. If it takes fire in the hand, it inflicts such severe burns, that it should never be handled out of water, if possible. When it burns in air it combines with oxygen, forming white fumes called phosphoric anhydride, which unite with water to form phosphoric acid.

The low temperature at which phosphorus takes fire makes it useful in the manufacture of matches, which are lighted by simple friction on a rough surface. The pieces of wood are first gummed and sprinkled with sulphur, or steeped in paraffin, and are then tipped with a composition which is composed mainly of glue, phosphorus, and chlorate of potassium, the latter being a body which parts readily with its oxygen, and therefore assists the combustion. Men engaged in this manufacture are liable to a terrible disease, in which the bones of the face are destroyed, owing to the fumes of the phosphorus which is employed.

Of late years, however, a new method of making matches has been discovered, in which the workpeople are not exposed to this danger, and which has the additional advantage that the matches only ignite on the box, or upon a similar grit to that which is laid on the box.

Sir Benjamin Brodie discovered that if phosphorus is heated in an atmosphere containing no oxygen, and a very small piece of iodine dropped upon it, the whole mass undergoes a remarkable change. The phosphorus then no longer looks yellow and waxy, but is red and powdery; it no longer fumes in air, and may be heated to a very considerable temperature (500° Fahr.) before it is oxidized or burnt, but if very slightly rubbed with chlorate of potassium it detonates. The grit of the match-box is therefore mixed with red phosphorus, and the match-head tipped with a composition containing chlorate of potassium, so that the match if rubbed on the box readily takes fire; but as it contains no phosphorus itself, it does not ignite if rubbed against an ordinary rough surface.

The heat necessary to ignite a match is obtained, then, by friction, and friction has been in all ages and among all nations the principal means of obtaining flame and fire. Savages were accustomed formerly to sharpen a piece of hard wood to a point, which was inserted into another piece of soft wood and placed among some light chips. The pointed piece was then rapidly turned after the manner of a drill, until sufficient heat was obtained by the friction of the two pieces of wood to kindle the chips.

This method, besides being most laborious, requires no mean skill for its proper performance, and a most valuable advance was made by the introduction of the flint, steel, and tinder box.

When a piece of iron strikes a piece of flint or hard stone with considerable force it is often seen to strike fire, that is, to produce a spark, as may be observed when a horse's shoe strikes a stone in the ground at night. This spark is a piece of iron torn off and rendered so hot by the concussion and friction as to become red hot and unite with the oxygen of the air, becoming oxide of iron. The heat produced is sufficient to ignite the very small piece which is torn off, but not the larger mass of iron left behind, as would be the case if the air consisted of pure oxygen, and thus the rest of the shoe is not burnt. Such a spark falling on tinder, which is rag either partially burnt or soaked in nitre and dried, will cause the tinder to smoulder away, and from the smouldering rag a flame can be obtained by applying to it a piece of wood tipped with sulphur. The tinder was therefore kept in a box, and a flint was struck by a piece of steel in such a manner as to cause the spark to fall on the tinder, a feat by no means easy to perform, an unskilful person often being a long time before a light was obtained by these means.

Friction sometimes produces heat enough to cause a fire where it is not at all desirable to do so, and cases have occurred of machinery and railway trains being set on fire by this means, when the parts which rubbed one against another were not kept sufficiently greased to prevent friction. In these cases sufficient heat was produced to cause some part of the machine, which was made of wood and was in contact with the hot metal, to combine with the oxygen of the air and burn away.

When a knife-grinder, with his rapidly revolving wheel, causes sparks to fly off, he is in reality burning part of the knife which he is sharpening, the union of oxygen with the iron in the particles of steel which are ground off causing the sparks that are seen to fly about.

Sulphur or brimstone is a yellow solid found native and in combination with iron and other elements chiefly in the neighbourhood of volcanoes. It burns in air with a blue flame forming sulphurous anhydride. It is quite insoluble in water, but forms a liquid compound with carbon, in which it may be dissolved. It is used sometimes as a medicine, and with this view is often placed in lumps in the water which is given to dogs to drink; this is, however, it is needless to say, quite useless for the purpose for which it is intended, as none of the sulphur is dissolved in the water. In order that it may be taken into the stomach, the powder known as flowers of sulphur should be mixed with the animals' food.

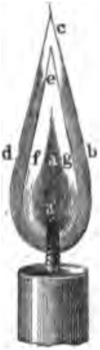
CHAPTER XIV.

FLAME — GAS — CANDLES.

All the different substances which are used for illumination are, with one or two exceptions, compounds of carbon and hydrogen, commonly called by chemists hydrocarbons. Coal gas, tallow, wax, paraffin, photogene, solar oil, and many others, are hydrocarbons; colza and other similar oils contain oxygen in addition. All these substances are burnt as gases, and all of them form water and carbonic anhydride by combining with oxygen in the air when they are burnt. When these substances are burnt in the ordinary manner the flame presents several remarkable characters, which are worthy of attention, because according as they are severally modified so the light and heat produced by the flame vary.

In the first place, then, the flame is hollow like a shell, the interior of the shell being filled with unburnt gas, as may be shown by holding one end of a small glass tube or piece of tobacco-pipe in the middle of the flame. Some of the unburnt gas will pass off through the tube and issue from the other end, where it can be lighted. Another experiment illustrating this is to cut the head off a wax match and hold it in the very middle of the flame on the end of a knife, when it will take some time before it is kindled. Gunpowder, too, may be held in a flame, if it is very quickly introduced, and held upon a piece of broken porcelain. If a splinter of wood be held directly across the flame, so that it shall run through the dark part, that part which is in the middle will be unburnt, while the wood will take fire on each side, where it touches the outside of the flame. Again, a sheet of good glazed note paper may be depressed on the flame in the same manner as the gauze in Fig. 30, and on its being raised again there will be seen a ring blackened and singed, with the centre not discoloured. These experiments all tend to show that there is no great heat in the interior of a flame. Careful observation will show that there are three distinct parts in a flame, as represented in Fig. 34. A dark space inside *a a′*, composed, as we have seen, of unburnt gases coming from the wick or jet; a bright envelope, *f e g*; and an almost imperceptible outer envelope, *b c d*. Some observers describe a fourth portion, a light blue zone which surrounds the wick at the bottom of the flame, and answers to the lower fourth of *d c b* in the drawing.

Fig. 34.



That part of the flame in which the most complete combustion is going on is the envelope *b c d*. Here the oxygen of the air has free access to both carbon and hydrogen, and both are completely burned there. In the envelope *f e g* the hydrocarbons meet with only a limited supply of oxygen, as the oxygen has first to come through the envelope *b c d*, where combustion is going on. The consequence is that there the combustion is incomplete, and the hydrogen, having a greater affinity for oxygen than carbon, separates from the carbon, and forms water, while the heat formed thereby makes the particles of separated carbon white hot. This is the cause of the luminosity of that envelope. The carbon particles as soon as they reach the outer envelope meet with more oxygen, and these are burned, forming carbonic anhydride. No oxygen reaches the inner cone at all, and consequently there is no combustion going on there, as was shown above. The envelope *b c d* is, however, feebly luminous, and this is said to be due to the air which is raised to incandescence by the heat of the combustion.

If a cold body, such as a piece of porcelain, be held in the flame, it will cool the particles of carbon down below the temperature at which they burn, and they are deposited upon it in the form of soot.

As the brightness of a flame is caused by solid particles of carbon, it follows that the more particles there are separated and raised to a white heat, the brighter will be the flame. For example, the flame of alcohol is dull and feeble, because alcohol contains comparatively little carbon, and the oxygen of the air can consume it at once with ease. But if a jet of chlorine gas is thrown into the middle of the flame it at once makes it bright, because it keeps the oxygen out, and at the same time only combines with the hydrogen of the alcohol, and so causes a separation of carbon.

It is possible, however, to have more carbon separated than can be heated to incandescence in the flame, or the supply of oxygen may be insufficient to carry on combustion rapidly enough to give the required temperature to the carbon; when this is the case the flame is dull and smoky. This is often exemplified in lamps which burn paraffin oil. If they are not turned up high enough the flame does not supply sufficient heat to raise the carbon to the required temperature, and if they are turned up too high the supply of oxygen is not sufficient for the proper combustion of all the materials composing the flame.

The flame of coal gas is similar to that of a candle if the burner has a round hole, but the burners generally used alter the shape of the flame, so that it is difficult to observe the different parts. The object of the modified shape of the flame is to cause a greater separation of carbon, and so increase the brightness of the flame.

If the flame of an ordinary burner is applied to a cold surface in order to heat it, some of the carbon is deposited upon it in the form of soot. But this deposit of soot means imperfect combustion, and consequently waste of fuel. If it be desired to obtain all the heat which the gas can give by combustion, it must be so arranged that it is *all* burnt. This may be managed by an arrangement seen in Fig. 29. A piece of wire gauze is supported an inch or two above the gas jet, so that as the gas streams upwards it becomes well mixed with air, and a light is applied at the top of the gauze. The resulting flame is extremely hot, and almost colourless; no bright particles of carbon will be seen in it at all.

A more convenient arrangement is the burner devised by the German chemist Bunsen, which consists essentially of an iron tube, about three inches long, open at both ends, into the lower end of which a gas jet enters for about three quarters of an inch. The gas issuing from the jet draws air from below with it up the tube, becomes mixed with the air in its passage, and burns with a colourless flame at the top. The lower end of the tube has generally a contrivance for regulating the size of the opening, so that the proper amount of air may be drawn up for the size of the flame required; as if too much air is admitted an explosive mixture is formed in the tube, and the flame descends to the jet below; if, on the contrary, too little air finds its way up, the flame becomes luminous, and deposits soot upon cold bodies held in it.

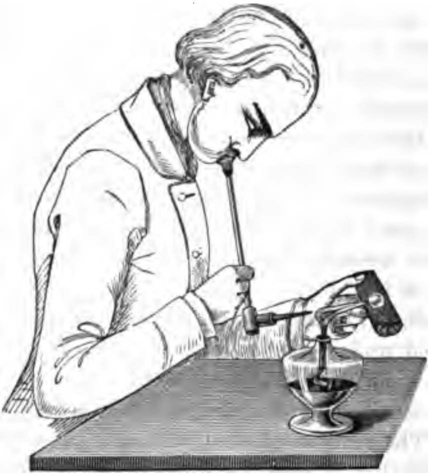
These different properties of a flame are often utilised by chemists, and made to assist various chemical changes which are required, and, by making use of a special artifice, are severally intensified or diminished according as the occasion demands. The instrument used to modify the supply of air to the flame is called a "blowpipe," and is represented in Fig. 35, where a man is depicted blowing on to a flame in order by its aid to effect the reduction of a metal from one of its compounds placed on a piece of charcoal.

The blowpipe is used on a flame for two different objects, independently of its heating effect; namely, to induce oxygen to unite with substances, and to take oxygen away from substances. In order to see how these two opposite results may be produced it will be necessary to examine the effect which the stream of air from the nozzle of the pipe has upon the flame.

The flame itself should be, if possible, a gas-flame issuing from a long narrow slit, or if gas cannot be used the flame of an oil lamp with a flat wick, or a spirit lamp in which the spirit is mixed with a little turpentine, so as to render the flame luminous.

The stream of air must be continuous, not in jerks or puffs: in order to effect this, the air must not be forced up direct from the lungs, but the mouth must be made a reservoir, and the force necessary to expel the air must come from the cheeks alone. This arrangement will offer no impediment to the ordinary breathing, and a little practice will enable any one to keep up a proper stream for an indefinite length of time.

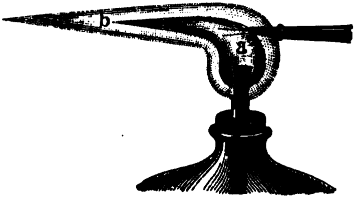
Fig. 35.



If now a gentle stream be directed on to a good-sized flame the character of the flame will be very little changed, but the temperature will be increased. A body held in the middle of the flame, in the midst of combustible gases and surrounded by glowing particles of carbon, will be in a very favourable position for parting with any oxygen which it may contain, and therefore this kind of flame is called the *reducing flame.*

If, secondly, the nozzle of the blowpipe be placed further in the flame, as shown in Fig. 36, and a moderately strong blast be driven through the flame, the flame will consist of two portions, a bright luminous portion *a a′*, and a faint blue portion *b c*. The combustion is incomplete in the portion *a a′*, on account of the cooling effect of the air which is driven through, and consequently this part of the flame has more or less of the character of the reducing flame.

Fig. 36.



By the time, however, that the air has reached *b c* it has become heated and ready for combustion. In this portion, therefore, the combustion is complete; there is besides an excess of hot oxygen in a favourable condition for combination, and therefore this flame is used for oxidising bodies, and is called the *oxidising flame.*

In Figs. 35 and 36 are examples of a reducing and an oxidising flame respectively; in the one the blowpipe is held outside the flame altogether, in the other the nozzle is inserted into the flame. The substance being reduced in Fig. 35 is placed on charcoal, because the charcoal, being heated by the flame, is ready to combine with oxygen, and therefore assists in the reduction of the metal.

All the different contrivances for burning oil and gas have for their object the supply of the proper amount of air to the flame, some of them causing the air to impinge upon the lower part, so that the pale portion, consisting of unburnt gases only, may be as small as possible, some confining the heated current of air surrounding the flame by a chimney, so that the upper part receiving a greater supply of oxygen may not smoke.

In candles the fuel is burnt in the form of gas. The heat of the flame melts the tallow or wax, which then rises up the wick in virtue of a mechanical property of surfaces in contact with each other, known as *capillary attraction*, and is there converted into gas and burnt.

CHAPTER XV.

ACIDS — SALTS.

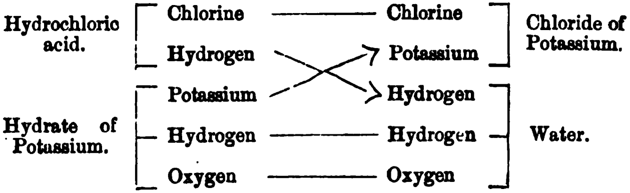
The term acid was originally applied to bodies which had a sour taste, the word acid meaning in Latin "like vinegar," and afterwards became to mean a corrosive body also.

The test of acidity was then considered to be the power which a body had of neutralising the effect of an alkali upon litmus and other vegetable colours, and of being itself neutralised by an alkali. An acid turns blue litmus red, and an alkali turns yellow turmeric brown, and restores the blue colour to litmus previously reddened by an acid (see p. 38). But an acid and an alkali can be mixed together so that their combined effect is *nil* upon litmus or turmeric, and the mixture is then said to be neutral.

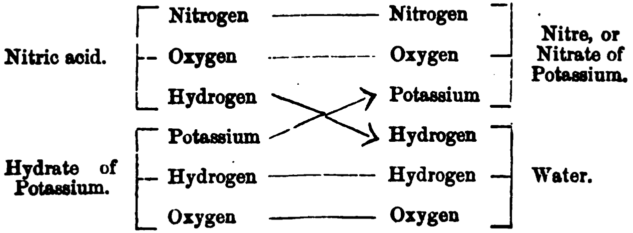
When oxygen was discovered, the properties of acids were attributed to that body, as all the acids then known were found to contain oxygen. Hence the name oxygen, or "acid-maker," was given to it; and hence, too, those oxides which have been mentioned in chapter vi. as forming acid solutions in water, were termed anhydrides, as they were considered to possess the essential part of an acid in them, which only needed the presence of water to become manifest. The discovery, however, of the body now called hydrochloric acid presented a difficulty in the way of this theory, which was met by assuming chlorine to be an oxide of a body termed murium, and hence the acid was called muriatic acid, a name by which it is still known. But the discovery of iodine and bromine, and the acid compounds of hydrogen which they form (chapter xi.) overthrew the theory altogether, and it was then that chemists remarked that the one body common to all acids, the loss of which destroys their properties, is not oxygen, but *hydrogen*, as is illustrated in the subjoined list:

Hydrogen Chlorine	Hydrochloric acid. (Chlorides.)	Hydrogen Chlorine Oxygen	Chloric acid. (Chlorates.)
Hydrogen Sulphur	Hydrosulphuric acid. (Sulphides.)	Hydrogen Sulphur Oxygen	Sulphuric acid. (Sulphates.)
Hydrogen Nitrogen Carbon	Hydrocyanic acid, or Prussic acid. (Cyanides.)	Hydrogen Nitrogen Oxygen	Nitric acid. (Nitrates.)

There are certain bodies, one of which is the hydrate of potassium, which react upon acids by exchanging a metal for hydrogen, forming a salt of the acid and water, thus:



Again;—



The column on the left represents the bodies *before*, that on the right represents them *after* the reactions (page 52).

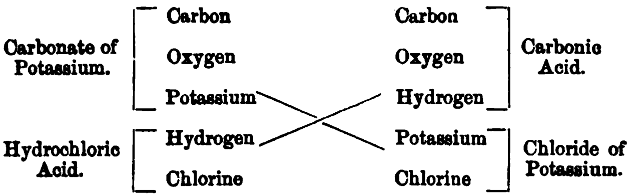
In these reactions hydrogen and potassium change places, and, consequently, in potassium hydrate there is half as much hydrogen as in water.

A reaction in which both bodies are changed by mutual action, is often called a *double decomposition*.

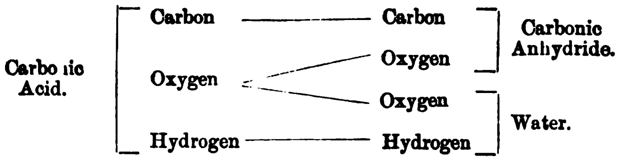
A salt, then, is the result of exchanging hydrogen in an acid for a metal, and the name of a salt is made to indicate from what particular acid it is derived. Thus, a salt derived from hydrochloric acid is called a chloride, from hydrosulphuric acid a sulphide, from sulphuric acid a sulphate, from nitric acid a nitrate, and so on. If the salt or acid contain oxygen, the last two letters are *te*; if not, they are *de*. Of those which end in *te*, if there are two or more acids made up of the same components, but containing different amounts of oxygen, the salt derived from the acid which contains the most oxygen usually ends in *ate*; the next in order, *ite*; the next ends in *ite*, and has also the prefix *hypo*. Thus there are three acids all containing hydrogen, phosphorus, and oxygen—phosphoric acid, phosphorous acid, and hypophosphorous acid. The salts of the first are called phosph*ates*; of the second, phosph*ites*; and of the last, *hypo*phosph*ites*.

One of the reasons which led chemists of former days to consider anhydrides as acids without water, was the fact that they have an acid taste. But this no doubt is due to the fact that when they are placed in the mouth they come in contact with moisture, and, consequently, an acid is formed there. An anhydride—carbonic anhydride, for instance—will not redden *dry* litmus paper, but hydrochloric acid gas will do so with ease.

An acid, then, may be described as a body which, firstly, contains hydrogen and is capable of reacting with hydrate of potassium, exchanging hydrogen for a metal, while at the same time water is formed; which, secondly, changes the colour of blue litmus to red; which, thirdly, causes effervescence with carbonate of potassium or sodium. The effervescence in the last case is due to the evolution of carbonic anhydride, and is caused thus: A carbonate is a salt of carbonic acid, which is a very feeble acid, and is capable of being turned out of its compounds by almost any other acid. Carbonic acid, then, is first formed, and the greater part of this is at once decomposed into carbonic anhydride and water, the gas coming off in bubbles. (See also page 28.)



and then



CHAPTER XVI.

SULPHATES—SULPHIDES—NITRATES—CHLORIDES.

SOME of the most important acids will now be enumerated together with their principal salts.

SULPHURIC ACID is a dense, colourless, oily-looking liquid, most strongly corrosive, and with a powerful attraction for moisture. When mixed with water, great heat is produced, indicative of the fact that it combines chemically with the water, and is not a mere solution. So strong is its attraction for water, that it will attract the water-gas from the air, and is therefore used by the chemist to dry air or gas when it is required free from moisture. Of course it can only be used when the gas has no action on the acid. For instance, it may be used to dry hydrogen (see page 7, where the drying-tube referred to contains fragments of pumice stone moistened with sulphuric acid), but it is not available for drying ammonia, as ammonia will be absorbed by the acid, and form a salt named sulphate of ammonium. Wood was said on page 20 to consist of carbon, and of oxygen and hydrogen in the proportion to form water. If a splinter of wood be dipped in strong sulphuric acid it will be charred, the acid separating the water from the wood, and leaving the charcoal, which is unacted on by this body. Sulphuric acid is made in large quantities for various chemical purposes, both in England and on the Continent, thousands of tons being manufactured every year. Sulphuric acid consists of hydrogen, sulphur, and oxygen, and is thus formed:

When sulphur is burned in air, a pungent gas is produced, of considerable bleaching power, known as sulphurous anhydride. When this anhydride dissolves in water it forms sulphur*ous* acid, a body which contains less oxygen than sulphuric acid. If, however, this gas be brought in contact with moisture in the presence of one of the higher oxides of nitrogen, it becomes oxidised at the expense of the oxide of nitrogen, and then forms sulphuric acid.

To effect this action on a large scale, sulphurous anhydride is formed by burning sulphur or iron pyrites (sulphide of iron), and is conducted, together with one of the oxides of nitrogen, into an immense leaden chamber, into which jets of steam are also issuing. There the acid is formed.

Sulphate of sodium, or Glauber's salt, is manufactured in large quantities in the preliminary operations necessary for the production of soda (carbonate of soda).

Sulphate of copper is a beautiful blue crystalline body, formed by boiling copper in sulphuric acid, and is used in dyeing, especially in calico printing, and for agricultural purposes.

An experiment can be made with sulphate of copper to show that in the different sulphates the different metals are united to the sulphur and oxygen with different degrees of force. If some of this salt be dissolved in water, and the blade of a knife be held in the solution for a few minutes, on taking it out the blade will be found to be covered with a red coat, which is metallic copper. This has been separated from the acid, and its place taken by iron from the knife, the sulphate of iron resulting from this change becoming dissolved in the water.

This process has been used on an extensive scale for the extraction of copper, hundreds of tons of iron being dissolved in pits containing a solution of sulphate of copper, sulphate of iron and metallic copper being formed in the process.

Sulphate of calcium is the most abundant of all the sulphates, and being found in large quantities near Paris, where it was first used as a plaster, has received the name of plaster of Paris; it is sometimes also called gypsum.

The forms in which this substance is found in nature are often exceedingly beautiful. Alabaster, which is cut into vases and ornaments, is one of them; another is satin spar, so named from the delicate white fibres in which it is arranged.

Sulphate of calcium in the form of gypsum is combined with water, about a fifth of the weight of gypsum being due to water. The water can be driven off by heat, but will again combine with the salt and form a solid mass. This is turned to account in making plaster casts. The powdered sulphate, from which the water has been expelled, is dropped into a basin of water until some of it remains dry at the top and no longer sinks to the bottom, and is then stirred and kneaded with the fingers for a few minutes. Soon the mixture becomes pasty, and is then run into moulds, the interior of which have been washed with soap-suds to prevent the cast from sticking, and in a very short time the whole will become a solid mass, which, in the course of a few hours, will be quite dry and free from moisture. In this process the water does not pass off to any great extent into the air by evaporation, as it does when a wet cloth is dried, but becomes part of the solid material itself.

Sulphate of calcium is the cause of *permanent* hardness in water; this will be again referred to in the chapter on soap.

Alum is a sulphate; but in this salt the hydrogen of the acid is replaced partly by potassium and partly by aluminum, and alum is consequently termed a *double* salt.

Sulphate of magnesium is the medicine known as Epsom salts.

Three of the sulphates are called in common language vitriols; sulphate of copper is *blue* vitriol, sulphate of iron is *green* vitriol, and sulphate of zinc is *white* vitriol, from the colours which these bodies have respectively.

Hydrosulphuric acid is a compound of hydrogen and sulphur; it is a gas with the smell of rotten eggs, which burns in air, forming water and sulphurous anhydride. It is obtained by acting upon proto-sulphide of iron with sulphuric acid, and is usually kept in solution, as water dissolves it freely.

There are two sulphides of tin, one of which, the bisulphide, is the body called *mosaic gold*. It is used to imitate bronze, and is valued for this purpose, because scarcely any acid will act upon it.

Sulphide of arsenic is a yellow substance used as a pigment.

Sulphide of silver is chiefly interesting because it is the tarnish formed upon silver in rooms where gas is burnt, hydrosulphuric acid being often present as an impurity in coal gas. A silver spoon cannot be used for eating eggs, because the eggs contain more or less hydrosulphuric acid (the cause of the smell of rotten eggs), which acts upon the silver. Egg spoons are usually, therefore, gilt, gold being unacted on by this acid.

NITRIC ACID is formed by heating nitrate of sodium or potassium with sulphuric acid, when sulphate of the metal remains in the flask, and nitric acid distils over as a nearly colourless limpid liquid. For this purpose an arrangement similar to that represented in Fig. 32 may be used.

Nitric acid is an extremely corrosive acid, staining the skin and animal textures yellow, and dissolving most metals, with the exception of gold, platinum, and one or two very rare substances.

The most important of the salts of nitric acid is the nitrate of potassium, or, as it is generally called, *nitre*, or sometimes *saltpetre*. This salt is found native in considerable quantities, especially in India; but a large amount is prepared artificially from animal refuse, by a process called *nitrification*. The principal use of nitre is in the manufacture of gunpowder, of which it is a most important constituent. Gunpowder is a mixture of nitre, sulphur, and carbon, in various proportions according to the purpose for which it is intended, and its properties depend upon the fact that it contains in itself the materials necessary for its combustion, and that it produces very rapidly a quantity of gas more than a thousand times as bulky as itself, which consists for the most part of nitrogen, and of carbonic anhydride or carbonic oxide, according to the proportions in which the different constituents of the powder are mixed. The nitrogen and oxygen are derived from the nitre. When a spark is applied to the powder, the heat is sufficient to ignite the grain upon which it falls, and this grain in burning produces heat enough at once to kindle the grains in contact with it, and thus the chemical action is almost instantaneously communicated through the whole mass.

Nitre is also largely used in agriculture as a manure, supplying the growing plants with nitrogen, and some of the constituents of the soil with oxygen.

Nitrate of silver is a white crystalline salt, used in photography, and in making indelible ink, on account of the action which light has upon it. The stains of this salt can be removed from the fingers or from linen by a solution of cyanide of potassium or hyposulphite of sodium. The *lunar caustic* used by surgeons is nitrate of silver, heated until it melts, and then run into moulds, so as to be used in the form of sticks.

Hydrochloric acid (see page 51) is obtained from common salt by acting upon it with sulphuric acid, the result of the reaction being sulphate of sodium and hydrochloric acid. It is usually kept as a solution in water, which solution will dissolve most metals, with the exception of gold and one or two others. Gold, however, may be dissolved by this acid if a few drops of nitric acid be added to the liquid, and the mixture is termed *aqua regia*, or "royal water," from the circumstance that gold is considered the king of metals, and can be dissolved only by this mixture.

Chloride of sodium, the most important salt of this acid, has been described on page 53.

There are two chlorides of mercury, one of which, calomel, is not dissolved by water; the other, corrosive sublimate, is easily dissolved, and it contains twice as much chlorine as calomel. Calomel is much used as a medicine, while corrosive sublimate, probably because it is so easily soluble, acts as a very irritant and powerful poison.

The chlorides generally are much used in medicine, and owe their efficacy chiefly to the power that they have of decomposing hydrosulphuric acid and sulphide of ammonium, which are often the products of an unhealthy body. The chlorine takes the hydrogen from these substances, and by thus breaking them up renders them harmless.

The chloride of lead is one of the most valuable deodorising substances known, and owes its power to the same circumstance, namely, the decomposition of bodies containing hydrogen. It is, however, dissolved only to a small extent by water; but a sufficiently strong solution may be prepared by dissolving some nitrate of lead (a soluble salt) in water, and then throwing into the solution some chloride of sodium. Chloride of lead is thus formed, and is held to a certain extent in solution, the excess giving the fluid a milky appearance. The water will become only *slightly* milky if enough water is used, but this milkiness will soon settle, and the solution will then be ready for use.

CHAPTER XVII.

CYANIDES — ACETATES — CARBONATES.

Prussic or hydrocyanic acid, the body referred to in the eighth column of the table on page 23, is a colourless, transparent, and very volatile liquid. It is intensely poisonous, and consequently dangerous to deal with; experiments upon it ought always to be conducted before an open window, and it should be used in very small quantities. It burns with a purple-tinted flame, resembling that of cyanogen (page 38), forming water, carbonic anhydride, and nitrogen. A gallon of this gas in burning produces a gallon of carbonic anhydride, half a gallon of nitrogen, and half a gallon of water-gas; consequently, the constitution of water and carbonic anhydride being already known (pages 24 and 30), it may be inferred that a gallon of prussic acid contains half a gallon of hydrogen and half a gallon of nitrogen, together with as much carbon as there is in a gallon of carbonic anhydride.

Prussic acid is obtainable from peach kernels and bitter almonds, and from laurel leaves, peach blossoms, and many other plants. Its odour resembles that of cyanogen.

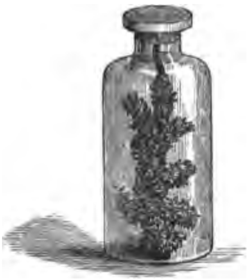
The iron salts of this acid are remarkable for their brilliant colours, prussian blue being among the number; but their composition is not so simple as the salts of other acids hitherto mentioned, and is too complex and difficult to be entered into in this treatise.

Acetic acid is the acid contained in vinegar, and consists of carbon and of hydrogen and oxygen in the proportion to form water. Strong oil of vitriol or sulphuric acid turns it black, taking away the hydrogen and oxygen in consequence of its powerful affinity for water, and leaving the black carbon free.

Acetic acid is prepared from alcohol by adding to it oxygen, or, in other words, oxidising it. On the continent wine is generally used in making vinegar (hence the French word *vinaigre*), but in England malt is used. For this purpose the wine is exposed to a gentle heat in large casks, having a small hole at the top to admit air. A ferment is added to promote the change more rapidly. The amount of acetic acid in vinegar is very small, a hundred gallons of vinegar containing from two to five gallons of acetic acid, the remainder being chiefly water.

Acetate of lead is the salt known as sugar of lead, so named on account of its sweet taste. A pretty experiment can be made with this salt, in the formation of what is called the lead tree. Dissolve half an ounce of the salt in a phial of six ounces of water, adding a little good vinegar if the solution is not quite clear. Fasten in the cork a strip or rod of zinc, as seen in Fig. 37. The zinc will soon appear to have little spangles on it, and these, gradually branching out in all directions, form a sort of tree, which is made of the metal lead. The zinc replaces the lead in this experiment,[1] forming acetate of zinc, which is dissolved in the water.

Fig. 37.



Verdigris is the acetate of copper, a green-coloured salt used in painting, and excessively poisonous. In order to prevent the formation of this compound, cooking vessels made of copper are lined with tin, otherwise the food, especially if it contained vinegar, would be poisoned.

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[1] This tree can be made to have different shapes by a little contrivance. Fasten a small lump of zinc to the under side of the cork by a string through the cork. Then fasten to the zinc fine brass or copper wire, which can be branched out in various directions. Crystals of lead will collect on these branches, and give a more perfect tree-shape than the slip of zinc.

Carbonic acid, as was stated on page 28, has never been obtained in a state of purity, but its salts are many of them very important.

Carbonate of calcium appears in various forms, as chalk, marble, limestone (a valuable material for building), Iceland spar, etc., and is the principal constituent of shells and of coral.

Carbonate of calcium does not dissolve very readily in pure water, but it is held in solution by water which is charged with carbonic anhydride. Spring water, which always has more or less carbonic anhydride in it, in the neighbourhood of limestone hills, dissolves a good deal of this substance, which crusts over stones and sticks. Caves in these regions sometimes present beautiful formations of limestone, from water in which it has been dissolved. As water drips from the roof it evaporates, and leaves behind some carbonate of calcium, which projects downwards, and gradually becomes a long pointed stick very much like an icicle, called a *stalactite;* at the same time, the water which drips on to the floor beneath evaporates, and thus a little hillock is formed of the limestone immediately below the stalactite, and is called a *stalagmite.* These formations, when they have been going on for some length of time, attain a considerable size, and the cave presents a most splendid appearance when lighted up, looking like a scene of enchantment.

Carbonate of calcium often becomes a serious inconvenience in water which is used for boilers; the carbonic anhydride is expelled from the water by heat, and the carbonate, then no longer soluble, forms an incrustation on the sides of the boiler. This may, however, be entirely remedied in water which is not intended for drinking purposes, by adding chloride of ammonium to the water, in which case carbonate of ammonium is formed and is driven off by the heat, while the chloride of calcium is dissolved in the water. Another plan, invented by Dr. Clark, consists in adding to the water in a tank, before it is introduced into the boiler, some hydrate of calcium, or milk of lime. This combines with the carbonic anhydride of the water, forming carbonate of calcium, and the whole is there deposited.

The *temporary* hardness of water is due to carbonate of calcium; it is called *temporary* hardness, because, unlike the hardness due to sulphate of calcium, it can be removed by boiling.

Carbonate of lead is insoluble in water, a fact which is important from the following consideration. Drinking water is commonly conveyed through lead pipes, and if it be quite pure, or at least containing nothing but air in solution, it dissolves the lead as oxide of lead, and becomes poisonous. If, however, as is generally the case, the water contains carbonate of calcium and carbonic anhydride, carbonate of lead is formed, and this, forming a crust on the pipe, protects it from further action. Thus, where the water is very pure lead pipes must not be used to convey it.

Carbonate of potassium is obtained from wood-ashes, and is the substance known in commerce as *potash*. It is used in making soap and glass.

Carbonate of sodium is prepared from common salt, and is known in commerce as *soda*. It is also used in making soap and glass.

The salts known as the bicarbonates of sodium and potassium have only half the hydrogen of the acid replaced by the metal.

Sal volatile, or smelling salts, is a carbonate of ammonium. Its name, sal volatile, is a Latin one, meaning flying salt, because part of this substance passes away spontaneously into the air, giving it the smell which it possesses.

As was stated in the chapter on acids, these carbonates effervesce with acids, giving off a gas which may be found to be carbonic anhydride.

Shells are made chiefly of carbonate of calcium, which is taken in by the animal as food, and deposited, after being removed from the blood, as an excretion. It may be seen that, in the case of an oyster-shell for instance, the shell is formed from the inside, and is not deposited by the water from the outside; for, of the layers of shell, which are easily recognisable, the outside one is the smallest, having been formed when the creature was young and small, and the inside one, formed by the large and full-sized fish, is the largest.

It sometimes happens that a hen lays an egg without any shell upon it. This is because she has not taken sufficient carbonate of calcium in her food; and care should be always taken, in keeping poultry, that they may have oyster-shells or chalk or some other form of this substance to peck at.

Coral is carbonate of calcium, deposited by very small animals as their skeleton. The animal grows, and makes continual additions to the top of its skeleton, while at the same time the lower part of its body is dying; thus a column of coral is built, the animal being always at the top. Millions of these little creatures, working together, have formed, in some parts of the world, extensive reefs of coral, but they do not raise their work above the level of the sea; as soon as they reach the surface they die. These reefs, however, in many instances become islands, by the continual washing up of materials from the sea, and from broken pieces of coral collecting in the middle of the reef. These islands are fertilised by seeds washed up by the sea, or brought there by birds, and so become fit for the habitation of man. Florida, in North America, has been formed in this way, and is still gradually growing by the labours of the coral animals.

CHAPTER XVIII.

SILICON — GLASS — EARTHENWARE.

SILICON is a body which is chiefly interesting on account of the compounds which it forms with oxygen and with fluorine, an element resembling chlorine, iodine, and bromine in many of its chemical properties.

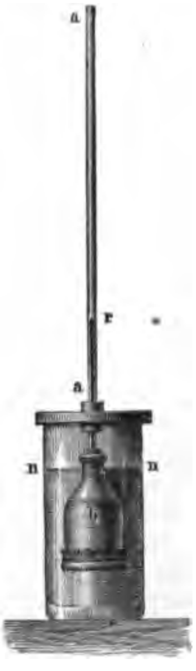
Oxide of silicon or silica appears in nature in a variety of forms, of which quartz, agate, flint, and sand may be taken as examples.

Although silica is not ordinarily soluble in water, nevertheless it is considered to be an anhydride, because there are salts known as silicates whose composition is found to correspond to an acid which would be formed if silica combined with water. This view is strengthened by the fact that it is possible to obtain a solution of silica in water, which has a feebly acid reaction on litmus paper. The way to do this is rather complicated, but instructive. Some carbonate of sodium is fused in a crucible over a furnace, and finely powdered silica is gradually dropped into it. Effervescence takes place, carbonic anhydride is given off, and a silicate of sodium is formed. If enough silica is added to decompose all the carbonate, when the product is dissolved in water, a solution of silicate of sodium is obtained. This must be largely diluted with water, and some of it added to a strong solution of hydrochloric acid. The result will be that the silicate will be broken up, and there will be in solution hydrochloric acid (which is in excess of that required to effect the decomposition of the silicate), chloride of sodium, and silica.

The silica may be now separated from the acid and salt by a process called *osmosis.*

The solution is placed in a tray of parchment fastened to a hoop, and floated on water for several days. At the end of that time the acid and salt will be found to have passed through the parchment into the water outside, and the silica will be left. The cause of this is not very well understood, but it belongs to a class of phenomena investigated by Graham, and called by him osmosis, from a Greek word meaning "impulse," in which it is observed that some substances have a much stronger tendency to pass through a porous partition than others. This may be well illustrated by the following experiment represented in Fig. 38: *b* is a jar whose bottom consists of a porous membrane, and which is in communication at the top with a straight glass tube, *aa*. The jar is filled with spirits of wine, and is suspended in a vessel *n n* containing water.

Fig. 38.



Gradually the water will enter the jar and cause the spirits to rise in the tube until it is quite full, overcoming the weight of the fluid, and the hydrostatic pressure which tends to keep the level in the jar the same as that in the outside vessel.

Silica is a very important constituent of certain plants. It exists in the stalks of grass; the ashes of the straw of cereals are more than half silica, but the ashes of the grain contain very much less, amounting, as a rule, to only one or two parts in a hundred.

The silicate of sodium is, as we have just seen, soluble in water; the same is true of the silicate of potassium; and when these substances are obtained from their solution they do not, like other salts we have met with before, appear in a crystalline form, but are perfectly structureless like solid jelly; these are termed soluble glass, and are used as a varnish or vehicle for the colour in certain kinds of pictures. The frescoes by Maclise, in the House of Commons, are treated with a varnish of this kind, though the result in this case is not so satisfactory as was anticipated, owing perhaps to some defect in either the material or the mode of its use. Silicate of calcium is not dissolved by water, and is crystalline; but if it is fused or melted with silicate of sodium or potassium, a substance is formed which is insoluble in water and acids, and at the same time is not crystalline; this is called glass.

Window glass is a mixture of the silicates of sodium and calcium, and is called crown glass or plate glass, according to the way in which it is prepared. The silicates of potassium and calcium form a glass which is difficult to melt, known as Bohemian glass, and is much prized for making certain kinds of chemical apparatus, to which it is desirable to apply considerable heat.

The silicate of potassium mixed with oxide of lead forms flint glass, a glass very easily melted, of which articles in common use, such as wineglasses and tumblers, are usually made. Coloured glasses are made by adding to the silicate certain metallic oxides; the colour of green bottle-glass, for instance, being due to oxide of iron. Enamel is glass mixed with oxide of tin, which makes it opaque and white, other oxides being added with the tin when it is desired to have a coloured enamel.

Clay is the silicate of aluminium, a substance which, as it is found in nature, forms a paste with water, and can be readily moulded into different shapes, but becomes hard and brittle under the action of heat. This property makes it available for pottery and brick making, for which purpose it has been employed among all nations from the most remote antiquity.

Bricks and flower-pots are made from a common sort of clay, which contains among its impurities iron, the cause of the red colour of the burnt brick. In the case of earthenware vessels which are intended to hold water, it is not sufficient merely to bake the clay, as it would then be left in a porous condition. In order to render it impervious to water it is glazed, either by dipping it in water containing a quantity of materials for forming glass, and afterwards heating it in a furnace, or by throwing into the furnace some common salt. This latter method is generally used for stoneware, which is a coarse kind of porcelain, and the way in which it operates is this. Common salt (chloride of sodium), although it is not decomposed ordinarily by heat, yet if it is heated in the presence of silica and of some substance that will both oxidise the sodium and at the same time combine with the chlorine (such as water, or oxide of iron, which will oxidise the sodium and form with the chlorine hydrochloric acid and chloride of iron respectively), becomes decomposed. The oxide of sodium unites with the silica in the ware, making silicate of sodium, which with silicate of aluminium forms a glass impervious to water, while the hydrochloric acid or chloride of iron is driven off by the heat. The oxide of iron here mentioned is often present in the clay as an impurity.

Fine porcelain, or china, is formed from a pure and white clay known as kaolin, which is found chiefly in China, although it is met with also in Cornwall and on the continent of Europe. In making porcelain the clay is intimately mixed with silicate of calcium and potassium, so that the glaze is not merely on the surface, but is uniformly blended throughout the substance of the ware with the material forming the vessel. A superficial glaze is added to give the surface a smooth appearance.

Meerschaum, of which pipes are made, is a silicate of magnesium.

CHAPTER XIX.

METALS AND THEIR OXIDES.

THE metals, about fifty in number, are those elementary bodies which by replacing hydrogen in an acid form salts, and they are distinguished as a class from other elements by certain physical properties, one of which is, however, possessed to a certain degree by a few of the opposite class.

In the first place, they are possessed of a peculiar shining appearance, which is called the metallic lustre, though iodine, and carbon in the form of blacklead, share this property with them. They are also *opaque* to light; that is, they do not allow light to pass freely through them, as glass does. This property also is common to many non-metallic bodies. Some of them possess in a remarkable degree the property of *malleability*, or of being hammered into very thin leaves, the word malleability being derived from the Latin word *malleus*, a hammer. The most remarkable instance of this is gold, which can be hammered out so excessively thin that considerably more than a quarter of a million of leaves must be laid one upon the other in order to measure an inch in thickness. Gold, silver, platinum, iron, and copper possess also *ductility*, that is, they can be drawn out into very fine wires. Some of the more important metals will now be considered, and the methods of obtaining them described whenever the process is instructive or interesting.

IRON is one of the most abundant of the metals, though it is seldom obtained chemically pure. The numerous and varied uses to which this metal is put render it one of the most valuable productions of the world, and one of the most interesting to the student of science. The ore from which most of our English iron is obtained is called *clay ironstone*, and is a carbonate of iron mixed with clay, lime, and many other impurities. From it we obtain three distinct classes of iron, whose properties depend mainly on the amount of carbon which is present in them.

Wrought iron is nearly pure iron, a hundred pounds of English wrought iron containing about half a pound of carbon. *Steel* contains rather more carbon, and *cast iron* still more; but the proportion varies very much in the two latter varieties, in cast iron varying from two and a half to five pounds in a hundred.

The properties of these three varieties of iron differ very materially. Cast iron is brittle, while wrought iron is tough, and will bend. Steel is brittle or flexible, according as it is cooled quickly or slowly after being heated. If red-hot steel be plunged into water, and in that manner quickly cooled, it becomes brittle, elastic, and extremely hard, almost as much so as the diamond; in order to render it more flexible, it is then heated again, and allowed to cool slowly, becoming more flexible the higher the temperature to which it is raised. In this second heating the surface appears of a different colour, according to the temperature attained, and by observing the colour the workman is able to judge of the amount of heat required for the purpose he has in view. Steel for razors is heated least, for knives more so, and for sword-blades and watch springs most of all; in the last case the steel often becomes so flexible that it can be bent double without breaking, and yet it is so elastic that it recovers its original shape exactly when the pressure is removed. This process is called *tempering* the steel. Wrought iron differs from cast iron in being *malleable*, *ductile*, and capable of being *welded*, that is, two pieces can be hammered together when hot so as to form one piece. When iron is heated it combines with the oxygen in the air, and a superficial layer of oxide of iron is formed on the pieces of hot metal, which would interfere with the joining of the two pieces of metal. To obviate this some sand is sprinkled over the metal, which forms a fusible glass called *slag*, by combining with the oxide of iron, and this, when the two pieces are welded together, is squeezed out from between them by the pressure.

There are several varieties of cast iron, of which the principal are *gray*, *mottled*, and *white*. In the gray and mottled cast iron, the carbon is not chemically combined with the iron, but is simply mixed equally throughout the mass, and in the mottled iron may be easily seen in small lumps or grains of graphite. In white cast iron, on the contrary, the carbon is chemically combined with the metal, and this form is more brittle and fusible than the others.

Gray iron is soft enough to be turned on a lathe, and when it is broken the iron appears arranged in little grains; its structure is therefore said to be granular. It is chiefly used for foundry purposes. If after being melted it is quickly cooled, it is converted into the white variety, and this fact is made use of in casting shot for cannon. The iron is run into iron moulds, instead of sand or earth, and consequently the surface is rapidly cooled, or *chilled*, as it is termed, and becomes extremely hard, so that it will penetrate very thick plates of iron without losing its shape.

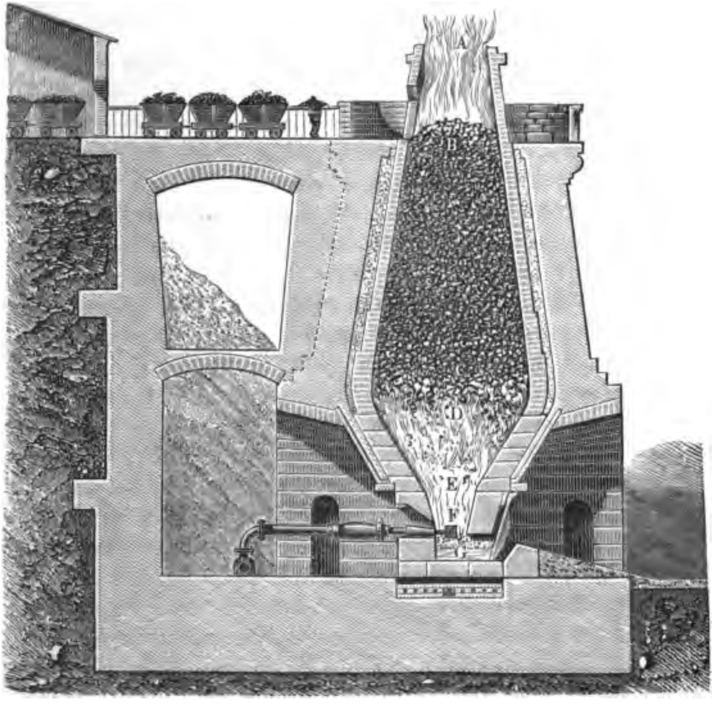
Besides carbon there is always in iron more or less silicon, sulphur, and phosphorus; but as these substances exercise a bad effect upon the metal, they are removed as far as possible in the process of extraction of the iron.

As steel and wrought iron are usually prepared from cast iron, it will be convenient to consider, first, the way in which cast iron is obtained from the ore.

This operation is technically called *smelting*, and is conducted somewhat as follows. The ore, which consists of carbonate of iron, with clay, lime, sulphur, phosphorus, magnesia, and other impurities, is first *roasted;* that is to say, a great heap is made of alternate layers of ore and coal, which is lighted and allowed to burn thoroughly. By this means the carbonate of iron is decomposed, and carbonic anhydride is expelled, together with water, and the greater part of the sulphur and phosphorus

The next stage of the process consists in removing the oxygen of the oxide of iron remaining from the decomposition of the carbonate, and of the other impurities. To effect this the roasted ore is heated in the presence of a reducing agent (page 71), and a quantity of material called a *flux* is brought in contact with it, which will form a slag with the magnesia, silicon, lime, and other impurities. This is effected in gigantic furnaces, one of which is represented in Fig. 39. The waggons at the top bring the

Fig. 39.



materials, which consist of roasted ore, coal, and limestone, and these are thrown into the furnace in successive layers. The furnace itself is lined with good fire-bricks, and is often kept lighted for years without going out. Air is driven into the furnace through immense blowpipes, one of which is seen at F, near the bottom. The melted iron collects at the bottom, G, where it is tapped off from time to time, while the impurities, forming a slag which is lighter than the iron, float on the surface, and run out of an aperture in the side of the furnace made for the purpose. The chemical changes in the furnace, beginning from the bottom, are these:

At F the oxygen of the air blown in combines with the carbon of the fuel and forms carbonic anhydride, producing a very high temperature. The hot gas rises up through the furnaces and heats the contents above. Between E and D the carbonic anhydride comes in contact with more fuel, and, both being of a high temperature, becomes converted into carbonic oxide (see page 27). Now carbonic oxide is a body which will burn if oxygen is supplied to it, and become reconverted into carbonic anhydride. This supply is afforded by the oxide of iron in the ore. At D, then, the ore gives up its oxygen, and the reduced metal sinks down to the bottom of the furnace, passing, as it does so, through the fuel which is burning, and taking up a small quantity of carbon. The heat produced by this action melts the impurities into slag, which also sinks down to the bottom. It has been found, that by blowing in hot instead of cold air ordinary coal can be used instead of coke, and that the quantity of fuel required to effect the reduction of the metal is much lessened, and a great saving effected thereby. But as coal contains sulphur and other impurities, which are not carried off in the process, the quality of the iron obtained is not so good as when coke or charcoal is used. A good deal of the carbonic oxide is not converted by the oxide of iron, and passes up to the top of the furnace with the carbonic anhydride formed in the process, and the nitrogen of the air which is driven in by the blowpipes, and is not changed. At the top the carbonic oxide is often burnt as shown in the drawing, and consequently wasted; but sometimes it is led away and utilised by being made to heat the air which is to be driven into the furnace. The iron which is run off at the bottom is cast in bars, which are termed *pigs*.

Cast iron is converted into wrought iron by depriving it of its carbon, silicon, and other impurities, by oxidising them and removing them as slags.

The two principal processes are called *refining* and *puddling*. In the former process, the pig iron is heated in contact with burning charcoal, air being urged upon the fire by a blowpipe, as in smelting. In the second, the iron is subjected to the action of flame and gases resulting from the combustion of carbon, without actually being in contact with the fuel.

Mr. Bessemer has proposed to substitute for these processes one in which cold air is blown into the melted iron, and thus the oxidation of the impurities directly effected. But it is found to be in practice a much more wasteful method, as a large portion of the iron also is oxidised, and therefore lost; neither does the process remove phosphorus and sulphur, and therefore it can only be applied to cast iron free from those impurities.

Steel, which contains a quantity of carbon intermediate between cast and wrought iron, is best made from wrought iron by adding the proper amount of carbon to it. Mr. Bessemer introduces the proper amount of carbon by adding to the wrought iron made by his process a certain quantity of pure cast iron; but generally steel is made by a process called *cementation*, which consists in heating wrought iron bars in contact with fine charcoal for several days.

A new process for obtaining steel and wrought iron from pigs consists in heating them in contact with nitrate of sodium. This process, called Heaton's process, effects the oxidation of the impurities quickly and effectually, and is much more economical of iron than the old methods; but it has not obtained the favour with iron-masters that chemists anticipated.

The two principal oxides of iron are the red and the black oxide. The first is known as *rouge*, the second as *loadstone*, and both are valuable ores of iron. The red oxide combined with water is the rust which forms on the surface of iron in a damp atmosphere.

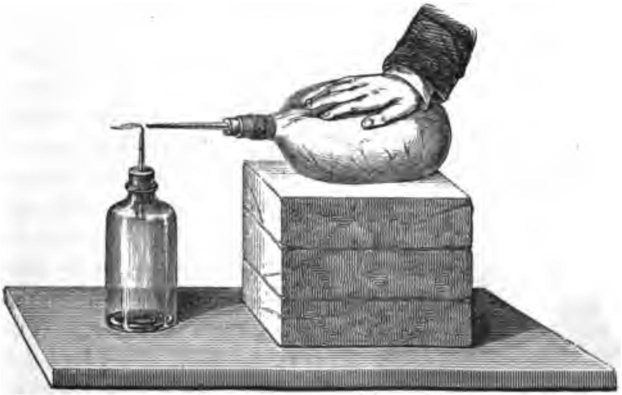
Nickel is a metal usually found with iron, and is one of the constituents of German silver, which is an alloy of nickel, copper, and zinc. An alloy means a combination of two or more metals, which, however, differs from an ordinary chemical compound in consisting of *any* proportion of its constituents. It appears to be intermediate between a mixture and a true chemical compound.

CHAPTER XX.

METALS AND THEIR OXIDES—*continued.*

Calcium. Lime is the oxide of calcium, obtained by heating limestone or carbonate of calcium in kilns, into which limestone and fuel are thrown alternately. Pure lime, or quicklime, is a hard, white substance, which can be raised to a considerable temperature without change; indeed, it has never been fused. A jet of hydrogen burning in pure oxygen, or a jet of hydrogen and oxygen mixed in the proper proportions to form water, produces intense heat, and if it is directed upon a piece of quicklime it raises the lime to a brilliant white heat, causing a light of dazzling brightness, which is used for signals at sea, and for illuminating the stages of theatres. Fig. 40 shows how this can be arranged. The bottle contains materials for making hydrogen, and the gas which issues from the tube at the top is

Fig. 40.

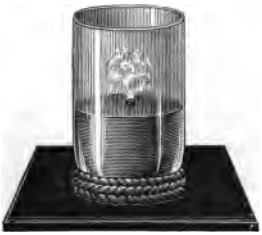


lighted. A stream of oxygen is then directed across the flame from the bag on the right side of the figure, and a piece of lime, not shown in the drawing, is held in the flame. Generally, however, the gases are made to issue both from the same jet, a special apparatus being used for the purpose, to prevent the mixed gases burning or exploding before they reach the mouth of the jet. This light is called the oxyhydrogen or lime-light, or sometimes the Drummond light, from its discoverer, Lieut. Drummond, R.N.

Quicklime has a great affinity for water, combining with it and forming a white powder called hydrate of lime, or *slaked* lime, which is, however, reconverted into quicklime by heat. This circumstance renders it useful to the chemist for the purpose of drying gases; but it must not be used for carbonic anhydride or acid gases, as it absorbs them and forms a salt of calcium. Mortar is slaked lime mixed with sand to give it hardness and consistency. When first made, mortar is soft and pasty, but gradually, as the union of the lime with water becomes complete, it becomes hard and firm. The part of the mortar exposed to the air absorbs carbonic anhydride and becomes still harder, while it protects the inner portions from further change.

Potassium and Sodium are metals which resemble one another very closely. They are soft like cheese, and, when freshly cut, of the appearance of steel. They have such a strong affinity for oxygen that they will decompose cold water, combining with the oxygen and setting free the hydrogen. The heat developed in this reaction in the case of potassium is sufficient to ignite the hydrogen, if the air is not excluded from it, the flame being tinged with a beautiful violet colour, due to some of the metal which is volatilised, or converted into gas and burnt at the same time. Fig. 41 illustrates this experiment.

Fig. 41.



The hydrogen set free by sodium will also burn if the metal be placed on blotting-paper, to prevent it running about on the top of the water and so cooling itself, the flame in this case being coloured yellow.

The oxides of these metals have also an affinity for water, combining with it and forming solid hydrates, which in their turn absorb water and carbonic anhydride, and form salts when brought into contact with acids (page 73). These hydrates act powerfully on the skin, and for this reason are termed *caustic* potash and soda. They also act upon glass at a high temperature, dissolving out the silica, so that none but common glass vessels should be used to heat them in.

Sodium and potassium are both obtained from their carbonates by heating them in retorts with charcoal, sodium being made in considerable quantities, as it is used for the extraction of the metals aluminium and magnesium. The ease with which these metals are oxidised renders it somewhat difficult to keep them, as they cannot even be kept, like phosphorus, under water. They are usually preserved in native mineral naphtha, a liquid hydrocarbon containing no oxygen.

ALUMINIUM is the most abundant of all the metals, though it never forms part of living beings, whether animal or vegetable. It exists in alum, clay, granite, and many natural rocks, and is one of the constituents of the emerald, garnet, ruby, sapphire, and other precious stones. It has very much the appearance of silver, is hard and tough, but is remarkably light, silver being about four times as heavy as aluminium; it can also be readily melted and moulded. On this account aluminium is much valued for making telescope-tubes and supports for optical instruments, and for ornamental work, such as cups and vases, for which purpose it is even better in some respects than silver; for it is with difficulty oxidised, and hydrosulphuric acid has no action whatever upon it at ordinary temperatures, so that it does not easily tarnish. Aluminium is prepared by heating its chloride with sodium, the chloride being first made to combine with the chloride of sodium so as to form a double salt. The chloride of aluminium is obtained by heating the oxide with charcoal in a current of chlorine.

The oxide of aluminium, or alumina, is found native, as the sapphire and ruby, and also may be obtained by adding ammonia to a solution of alum. Emery powder is impure alumina.

MAGNESIUM is a metal resembling aluminium in appearance, and is even proportionately lighter; but as it tends to combine with oxygen, and will become oxidised in moist air, it cannot be applied to the same purposes as aluminium. Nevertheless, its affinity for oxygen renders it useful in another way. If raised to a red heat in the air, magnesium will burn, giving out as it does so a light of dazzling brightness, which is found to be of the particular quality desirable for photography, and is therefore much used for photographing interiors of houses and places where daylight is not available. Magnesium is found in large quantities in the form of carbonate, combined with carbonate of calcium in *magnesian limestone;* it is also found in sea-water (page 56), in plants, and in animals. To extract the metal, the carbonate is treated with hydrochloric acid, and the resulting chloride is treated in an exactly similar manner to the chloride of aluminium in the preceding page. The metal, after it is extracted, is softened by heat, and drawn out into a wire or riband.

MANGANESE is interesting only through its compounds, one of which, the black oxide, has been already mentioned. If this is strongly heated it gives off oxygen gas, and is converted into another oxide which contains less oxygen. Besides being a source of oxygen, this oxide is used for giving a violet colour to glass. Manganese also appears like a non-metallic element in certain salts, which are called manganates and permanganates, the manganese in them answering to the sulphur in sulphates, or the chlorine in chlorates. Condy's fluid, used for disinfecting, contains permanganate of potassium or calcium, and depends its efficacy upon the ease with which it parts with oxygen

Lead is a soft metal, with little tenacity (that is to say, a wire of lead is easily broken), and is obtained from *galena*, the native sulphide of lead, by heating it in a furnace in contact with air. The sulphur is eventually burnt, and passes off as sulphurous anhydride, leaving behind metallic lead.

There are three oxides of lead, containing different amounts of oxygen. One, of a yellow colour, is called *litharge;* another, of a red colour, is used in painting and glass-making; the third is of a dark brown.

The uses of lead are various and extensive. It is used for roofing, and for water-pipes. Type-metal is an alloy of lead and antimony; shot and bullets are made of lead mixed with arsenic; solder is an alloy of lead and tin; and pewter is an alloy of the same kind, but of different proportions.

Tin is a bright white metal, very soft and malleable, which does not oxidise easily in the air. Tinstone, the ore of tin, is an oxide, from which the metal is obtained by heating it with carbon, so as to remove the oxygen. Tinware is iron coated thinly with tin by dipping it into molten tin. Common pins made of brass are whitened by boiling them in a solution of tin in tartrate of potassium (cream of tartar), alum, and common salt, which leaves a thin coating of tin upon them.

Copper is the only metal of a red colour. It is malleable, ductile, and tenacious, and does not readily oxidise. It is a good conductor of heat, and is therefore used for cooking-vessels, which, however, are always lined with tin, for reasons mentioned on page 84. It is obtained from several ores, chiefly from the sulphide or the oxide. The copper sulphide is always associated with sulphide of iron and arsenic, and it is first heated in contact with air until the arsenic is driven off and the iron converted to oxide of iron, which is removed as a slag. The copper sulphide is then more strongly heated, until the sulphur is driven off as sulphurous anhydride, and the metal left behind.

Brass is an alloy of zinc with copper; Bronze an alloy of copper and tin.

There are two oxides of copper, of which the black oxide is used in chemistry for the analysis of organic bodies containing hydrogen, which it removes by giving up its oxygen to combine with it and form water.

ZINC is a bluish-white metal, which does not oxidise easily in the air, and is therefore used for roofing, the lining of sinks, refrigerators, etc. It is brittle at ordinary temperatures, but it has been lately found to be malléable at about 130° Fahrenheit, which has rendered it available for the purposes mentioned; above this temperature, however, it again becomes brittle, and cannot be worked.

The ores of zinc are the sulphide (*blende*), the carbonate (*calamine*), and the oxide. Blende and calamine are heated in contact with air, so as to convert them into the oxide, which is then heated with carbon to expel the oxygen, and the zinc then passes over as vapour and is condensed.

ARSENIC is a lustrous, brittle metal, distinguished by the excessively poisonous character of its compounds, which renders any examination of them dangerous, unless unusual care be taken by the manipulator.

Some of the compounds are very brilliant in colour, and are used often in green papers, and in wreaths for ladies' hair, in consequence of which illness and even death have resulted from the absorption of some of the poison into the system.

The powder sold as *white arsenic* is an oxide of the metal, and being sometimes mistaken for sugar or salt, it has thus caused many untimely deaths.

The importance of being able to detect small quantities of this substance with ease and certainty will be obvious to every one; and fortunately the properties of arsenic and of one of its compounds are sufficiently remarkable to enable this to be done.

If any substance is thought to contain arsenic, a little of it should be placed in a test tube with some water and a few drops of hydrochloric acid, and boiled. If a clean piece of copper riband be held in the liquid for a few moments, a dark-gray deposit will be formed upon it, if arsenic be present. A piece of the coated copper should then be dropped into a tube like that represented in Fig. 42, and heated, when metallic arsenic will pass off in vapour from the copper, and be deposited in a lustrous ring in the cool part of the tube, as at *c*.

Another good and instructive method is to pour a little of the solution in hydrochloric acid, into a bottle in which hydrogen is being made. The hydrogen should be lighted as it comes out of the bottle, for the compound of arsenic which is formed is exceedingly poisonous to breathe, but is decomposed by heat. A piece of cold porcelain held in the flame, as shown in Fig. 43, will, if there be arsenic present, have a deposit of the metal upon it, which will be lustrous, easily driven off by heat, or dissolved by a solution of bleaching powder. The metal arsenic, when heated, passes off as vapour without melting, a process called *sublimation*.

Fig. 42.

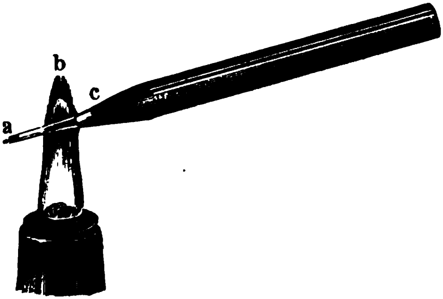
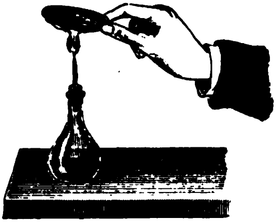


Fig. 43.



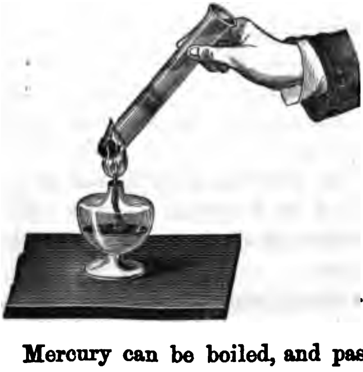
ANTIMONY is a metal very closely resembling arsenic in its properties, and may be detected by a similar test, the difference between the two being that in the case of antimony the deposit is not so lustrous, nor so easily volatilised or turned into vapour. Neither is it dissolved by bleaching powder; but it is, on the other hand, dissolved by a solution of sulphide of ammonium, which has no effect upon arsenic, forming a liquid which leaves a yellow residue when evaporated.

If arsenic and antimony are present together, when the copper is heated (Fig. 42), two rings will be formed in the tube, one above the other. Antimony, not being so volatile as arsenic, will be deposited first, and form a ring in a part of the tube which is not quite cold.

Mercury is a white metal, having a brilliant metallic lustre, and is the only one which is commonly liquid. It becomes solid in the extreme cold of the Arctic regions, and therefore in the expeditions of Dr. Kane and others to those regions thermometers containing mercury could not be used. They were obliged to have thermometers containing alcohol, which does not become solid even in very great cold.

Mercury is sometimes found pure. It is said that the mines in Mexico were first discovered thus: A hunter as he was ascending a mountain caught hold of a shrub to assist him; the shrub gave way at the root, and there ran from the ground a stream of mercury. It was supposed to be liquid silver, and therefore received the name of *quicksilver*.

Fig. 44.

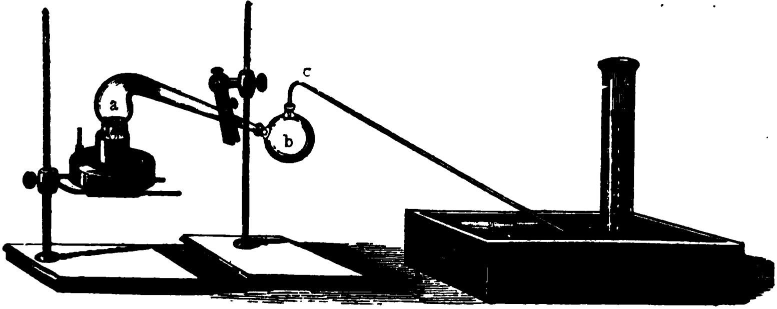


This metal is commonly obtained from the sulphide of mercury called cinnabar, which varies in colour from bright red to brown-red. Cinnabar when bright red is called vermilion, and is used to give a red colour to sealing-wax.

Mercury can be boiled, and passes into vapour. If this be done in a test-tube, the vapour will condense in the cool part of the tube in a ring, which is bright like a looking-glass (Fig. 44). Looking-glasses are silvered with an alloy of mercury and tin.

Although mercury can be boiled and distilled without change, if it is exposed to a moderate heat in contact with air for several days it becomes converted into a red powder, which is an oxide of mercury. The red oxide, if heated more strongly, gives off oxygen again. This experiment is interesting, as it was in this way that the chemist Priestley obtained oxygen, in the year 1774, the first gas ever discovered in chemistry. Fig. 45 shows how the experiment may be performed. The red powder is heated in *a*, and is decomposed into mercury and oxygen gas. The mercury vapour is condensed in the neck of the retort to a liquid, which runs down and collects in *b*, while the oxygen gas passes along the tube *c*, and is collected in the receiver placed in the pneumatic trough.

Fig. 45.



Silver occurs in nature sometimes pure, sometimes in alloys or mixtures with other metals, as lead, copper, etc., and sometimes united with sulphur or some other substance. The most famous mines are in Saxony, Mexico, and South America. This metal is very malleable and ductile. It is not so hard as copper, nor so soft as gold.

Gold is not found in nature united with other things, as many metals are; but either pure, or mixed with some other metals as an alloy. It is found in rocks, or sands that have been washed down by rivers.

Platinum is commonly spoken of as the heaviest of all known substances; but there is another metal, iridium, found in company with platinum, which is a little heavier. Platinum has a colour like steel. It is very ductile and malleable. No common fire can melt this metal; it can be melted, however, by the heat of the oxyhydrogen blowpipe.

Mercury, silver, gold, and platinum have been called the noble metals, because when pure and not formed into alloys they are not tarnished by the oxygen of the air.

At this point we may gather up our knowledge of oxides, which briefly amounts to this. Oxides may be divided into three classes, according to their action upon water. The first class, called anhydrides, unite with water to form acids, turning litmus red; such are nitric anhydride, nitrous anhydride, carbonic anhydride, sulphuric anhydride, arsenious anhydride, etc. The second class, termed basic oxides, unite with water to form hydrates, bodies which restore the blue colour to litmus which has been reddened by an acid; such are the oxides of potassium, sodium, calcium, etc. The third class do not combine chemically with water at all, but either form neutral solutions or are insoluble in water. Such are the oxides of gold, platinum, manganese, some of the oxides of nitrogen, carbonic oxide, etc. These last are called neutral oxides.

CHAPTER XXI.

SOLUTION — CRYSTALLISATION — ALLOYS — AMALGAMS.

THE force which causes different substances to dissolve in water or spirit differs in some important respects from the force which causes bodies *chemically* to unite with one another. In a simple solution both bodies retain their distinctive characters. For instance, a solution of sugar in water retains the sweetness of sugar and the liquidity of water, a solution of camphor in spirit retains the smell and tastes both of camphor and spirit, and the same is true of a solution of indiarubber in chloroform. This is quite different from the case of a metal dissolved in an acid, where the resulting salt differs altogether from the metal or the acid. Simple solution is caused not by *chemical* affinity, but by a force which is called by men of science *adhesion*.

In consequence of variation in the force of adhesion between substances, there is a great difference in bodies with regard to their facilities for solution. It has already been seen how differently the various gases behave in this respect; for instance, while nitrogen and oxygen are dissolved very sparingly in water, ammonia and hydrochloric acid are very soluble indeed. The presence of oxygen in water is however needful to the life of the fish inhabiting the rivers and ocean. They are able to extract the oxygen which is *dissolved* in the water (not that which is *chemically combined* with the hydrogen), and so obtain that supply of oxygen which is needful to the support of all animal life. Salts and other solids differ also among themselves almost as much as gases. Calomel, for example, which is a chloride of mercury, is perfectly insoluble; that is, not a particle of it can be dissolved in clean water. But corrosive sublimate, which is also a chloride of mercury, is very soluble. Magnesia, an oxide of the metal magnesium, is insoluble; but the oxide of the metal potassium is exceedingly soluble, having such an attraction for water that if left uncovered it becomes dissolved in moisture gathered from the air, and is said in consequence to be *deliquescent.* This latter oxide can be dissolved in half of its weight of water, while lime, which is the oxide of calcium, requires a thousand pounds of water to dissolve one pound of it.

This difference between bodies in regard to solubility is often of great use to man for very various purposes. For instance, lime is used in plastering walls, for which it would be of no use if it absorbed water from the air like the oxide of potassium. Carbonate of calcium, which appears in the forms of chalk, limestone, marble, etc., is only very sparingly soluble in water, and can therefore be used for buildings exposed to the air and rain, while carbonate of sodium is very soluble, and is used for cleansing purposes, causing dirt to be dissolved in water which would be insoluble without the presence of soda.

The feeble solubility of carbonate of calcium makes it a good material for the shells of fish. It would be very inconvenient for them to have their shell houses made of a substance which water could dissolve easily; at the same time, if carbonate of calcium were not soluble, it could not be taken into the blood of the animal and so formed into shell.

When water has dissolved as much of a substance as it can, the solution is said to be *saturated.* This word comes from a Latin word which signifies *to satisfy.* Water is more easily satisfied or saturated with some substances than with others. Oxide of potassium and lime are in strong contrast in this respect; half a pound of water will not be *satisfied* till it has dissolved a pound of oxide of potassium, while a thousand pounds of water will be *satisfied* or *saturated* with a pound of lime; that is, it takes two thousand times as much oxide of potassium to *saturate* water as it does lime.

It may be well to remember in passing that when oxide of potassium or calcium comes in contact with water it *combines* with it in the first instance, forming hydrate of potassium or calcium, and it is the *hydrate* which afterwards *dissolves* in the water.

Some solids can be mixed very thoroughly with water by reducing them to powder, and yet do not dissolve. Calcined magnesia is the oxide of magnesium obtained by driving off carbonic anhydride from the carbonate by heat, and this will mix readily with water, but it is not dissolved. A substance that dissolves disappears and nothing can be seen of it, except its colour, if it happen to be a coloured substance. The solution is clear and transparent, but a mixture is cloudy and opaque.

As a general rule more of a substance dissolves in hot water than in cold, though lime and some of the salts of calcium are exceptions to this. Boiling water will dissolve only about half as much lime as water which is near its freezing point. Glauber's salt too has the remarkable peculiarity of being most soluble at a temperature about a third of the way between the freezing and boiling points of water, its solubility decreasing upon either side of this temperature.

When water evaporates from a saturated solution of a salt, or when a hot saturated solution is allowed to cool, some of the salt becomes deposited as solid crystals on the bottom and sides of the vessel. Hot water dissolves twice as much alum as cold water, and when the water becomes cold half of the alum will become solid again. If a wire be suspended in the hot solution, as it cools the crystals will collect upon the wire. Baskets are sometimes made in this way of alum or other crystals; a basket of thin wire is suspended in a hot solution and crystals are formed round the wire.

Common salt dissolves as freely in cold as in hot water, and in consequence crystallisation is only produced by evaporation; that is, the water passes away as vapour into the air, and the salt being left reappears in its crystalline state.

The explanation of the phenomenon of crystallisation is not at present known, that is to say, the reason why the particles are arranged so as to make such very smooth surfaces and such straight edges. They are particles so small that they cannot be seen even with a powerful microscope, and yet, in making a crystal, each one takes its right place. Sometimes this arrangement of particles is quickly done. The most familiar example of this is in water, for sometimes on taking up a pitcher of water on a very cold morning, part of the water turns all at once into crystals, which shoot across in every direction, and can be seen if the water which remains fluid be poured out. The explanation of the phenomenon is easy: the water in the pitcher during the night became freezing cold, but it was perfectly still, and so the particles of the water remained still; but shaking the pitcher caused their arrangement in a solid crystalline form.

There is the same quick formation of crystals on a large scale in every snowstorm. Clouds are reservoirs of water from which snow is made, the water being in the form of fog; and particles of this fog are in a snowstorm continually arranging themselves in crystals, and so fall to the earth.

There are great varieties in crystalline arrangement. Mica is arranged in layers which can be peeled off exceedingly thin, and is used for windows in stove doors, the pieces employed for this purpose being made up of a number of these thin layers. Crystals of common salt are exactly square blocks, while crystals of Iceland spar are not square like those of salt, but sloping. These are but three of the very many varieties that occur in the shapes of crystals. Sometimes the same substance appears in different forms, as is the case with gypsum, and with water itself, the various forms and arrangements of whose crystals in snow and frost are very beautiful.

Some salts require to be united with a certain proportion of water before they will crystallise, although this is not the case with all. This union is not chemical union, but is something of the nature of adhesion, a force similar in kind to that between a salt and the water in which it is dissolved. Carbonate of calcium crystallises without water, but in crystals of carbonate of sodium there is more water than carbonate of sodium, a hundred pounds of the crystallised salt containing sixty-three pounds of water. Yet the crystals are dry, the water forming part of the solid substance. By heating the crystals the water is driven off from them, the salt first melting in its own water, and the salt is then no longer crystalline, but appears as a powder. The water which is necessary for the crystalline form of a salt is called by chemists the *water of crystallisation.*

Nitrate of potassium, or Saltpetre, has no water in it. If it had, it might not answer for making gunpowder. Nitrate of sodium has no water in it, and would do for making gunpowder as well as nitrate of potassium, were it not for one thing—it imbibes moisture from the air. This would not answer for gunpowder, for that must be kept dry. A salt which thus imbibes moisture is said to *deliquesce*—a word derived from a Latin word meaning to melt. A salt, on the other hand, which on exposure loses its water of crystallisation, and changes from a crystal into a powder, is said to *effloresce.* Crystals that do this have a mealy powder gradually forming on their surface. The word effloresce comes from the Latin word meaning to flower. It is as if the mineral flowered.

Many metals show crystals. In the formation of the lead-tree described on page 84, lead becomes crystalline, the tree being made of crystal joined to crystal. If a bar of tin is bent it gives a peculiar sound, which has been called *the cry* of tin and is supposed to be produced by the rubbing upon each other of the little crystals of which the metal is composed. The crystals of tin can be seen beautifully developed by a very simple process. Take a piece of ordinary tin, which is a sheet of iron covered with tin, and heat it over a lamp till the coating of tin melts; let it cool quickly, and wash the surface with a little *aqua regia,* the acid mixture mentioned on page 81.

Alloys are mixtures of metals which are united together by a force of the same nature as a solid and liquid in a solution, and not by chemical attraction; consequently the constituents of an alloy are not united in any definite proportions, but may bear any ratio whatever to one another; the properties, too, of an alloy bear always some relation to those of the metals which form it, and are generally intermediate to them. For instance, type metal formed of lead and copper unites the softness of lead with the hardness of copper, and is a substance intermediate in hardness between those two metals.

Many of the alloys have been already mentioned, but there are others which are commonly used, and must not be passed by unnoticed.

Pinchbeck, of which watch cases are sometimes made, is an alloy of copper and zinc, containing more zinc proportionately than brass, which makes it look like gold.

Tombac is another alloy of copper and zinc, which can be hammered into very thin leaves, making a spurious or false gold leaf. When finely powdered it is called gold bronze.

There is an alloy which is sometimes made a source of amusement. Teaspoons manufactured from it melt if introduced into hot tea. This alloy is composed of bismuth, lead, and tin; the proportions being, of bismuth 8, lead 5, and tin 3.

The gold and silver in common use are alloys. This is true both of money and of the articles made from these metals.

In the silver coin of England we have an alloy with copper, the object of the copper being to make the coin hard, so that it will not readily wear out. In 100 parts of our silver coinage there are 92½ parts of pure silver and 7½ parts of copper. Silver used for other purposes ought to have just this proportion of copper, in order to preserve a beautiful white lustre; for if there be more copper, the article made of the alloy will be tarnished, in consequence of the copper becoming oxidised when exposed to the air.

Gold is softer than silver, and to harden it sufficiently the gold coin of this country is alloyed with copper in the proportion of 11 parts of gold and 1 part of copper. Goldsmiths express the proportion of pure gold in its alloy by dividing it into 24 imaginary parts, which they call *carats*. If therefore it is said of any specimen that it is 16 carats fine, it is meant that 16 parts out of 24 are pure gold. So if it be said that a specimen is 18 carats fine, it is meant that of 24 parts 18 are pure gold.

The gold of our coinage is consequently 22 carats fine, and is called *standard gold*.

Amalgams are mixtures of mercury with other metals, with one of which you are familiar, namely the silvering on the back of glass in mirrors. This is an amalgam of mercury and tin. Tin foil, that is, tin leaf, is first applied all over the glass; then mercury in which a small quantity of tinfoil has been mixed is poured upon this, and uniting with the tin makes an amalgam.

Use is sometimes made of the affinity which mercury has for gold, in separating gold from substances with which it happens to be mingled. The material consisting in part of gold is powdered and then shaken with mercury, when the gold unites with the mercury forming an amalgam. Even when the material contains little gold, that little may be thus extracted. The gold that is in the dust of jewellers' shops is often recovered in this way.

In order to recover the gold from its solution in mercury, the solution is poured upon a closely-woven cloth, which allows most of the mercury to run through, the gold with a little mercury remaining in the cloth. Then by the application of heat this mercury is driven off in vapour and gold is left.

This is called obtaining gold by the process of *amalgamation*, a word you will often hear applied to other subjects. When people agree or unite readily in their views and plans they are said to amalgamate, as gold and mercury readily unite. Here is an extended use made of a word which was first only applied to one thing—a very good example of a way in which language is built up and enlarged.

CHAPTER XXII.

FAT—OIL—SOAP—CANDLES.

FATS and oils are bodies containing carbon, hydrogen, and oxygen, and are found in both animals and vegetables. The only difference between a fat and an oil is that a fat is solid and an oil is liquid at the ordinary temperatures of the air. Of the oils obtained from animals, those derived from man and the warm-blooded animals are generally solid, while those which come from fish and cold-blooded animals are usually liquid. The use of fat in the body appears to be chiefly to keep up its temperature, both by supplying combustible matter to the various parts of the frame (fat containing large quantities of carbon), and also, being a non-conductor of heat, by furnishing a coat as it were which shall prevent the heat generated in the body from escaping.

Of fats and oils derived from vegetables the following are the best known—olive oil, almond oil, colza oil, linseed oil, palm oil, cocoa-nut oil, and castor oil; of animal fats, sperm oil, cod-liver oil, neats' foot oil, lard, which is the fat of the pig, suet, which is the fat of the sheep or ox, spermaceti, bees'-wax, and butter.

Oils are not simple compounds, if the expression may be allowed, but are mixtures of at least four other compound bodies, three solids and a liquid; namely, *stearin*, *palmitin*, *margarin*, and *olein*.

Stearin, a name derived from the Greek word for suet, may be obtained from mutton fat by heating it with ether, which dissolves out the other components of the fat, and leaves the stearin in crystalline scales.

Palmitin is so called because it is found in considerable quantity in palm oil.

Margarin is the solid part of human fat and of olive oil, and is so called from its appearance, its name being derived from the Greek word for a pearl.

Olein is the liquid constituent of fats and oils.

Oils will not mix with, and are not dissolved at all by water; but if a solution of caustic alkali be shaken up with an oil, it forms a milky liquid in which the oil is mixed with the water, and does not separate from it as it does from pure water. This liquid if boiled for some time becomes clear, and when shaken up forms a lather.

The oil under the action of the alkali will have undergone a remarkable change, of which the following is an explanation. Stearin, palmitin, margarin, and olein are compounds of a body called glycerin with stearic, palmitic, margaric, and oleic acids respectively; and when the hydrated oxide of an alkali is boiled with them, they are decomposed, the glycerin is set free, and the acid forms a salt of the alkali metal which is the substance known familiarly as soap. This process of decomposing the oil is called *saponification*, and is carried on on a large scale in the manufacture of soap. The stearate and similar salts of the alkali are soluble in water, but insoluble in a solution of common salt. This fact is made use of in separating the soap from the glycerin after saponification of the oil. Strong brine, or solution of salt, is added to the liquid, when the soap curdles together and rises to the top, and the liquid containing the glycerin is drawn off from below.

There are many kinds of soap dependent on the nature of the oil and the metallic oxide used. *Hard soaps* are salts of sodium, *soft soaps* of potassium. Common soft soap contains an excess of alkali, which gives it a more powerful cleansing property than other soaps, and besides has usually not been freed from glycerin. Soap has a strong attraction for water, and even when hard may contain a third of its weight of water, a circumstance which is of advantage only to those who sell it. Common *yellow soap* is made of oil and soda mixed with resin.

Castile soap ought to consist of olive oil saponified with soda, and coloured blue and red with sulphate and oxide of iron. *Curd soap* is made of pure tallow and soda, and marine soap of cocoa-nut oil and soda. Fancy soaps are common soaps coloured and perfumed with aromatic oils. Streaked or mottled soaps are coloured with metallic oxides, chiefly oxide of iron, and as these cannot be properly worked into the soap when it is very soft, such soaps cannot contain a very large amount of water.

Calcium, barium, and strontium will also form stearates and other soap salts, and will turn out sodium and potassium from their soaps; but the soaps of these metals are insoluble in water, and therefore of no use whatever for the purpose of cleansing. What is termed the hardness of water is caused by the presence of a salt of calcium, which decomposes washing soap, and forms an insoluble soap itself; the calcium soap does not form a lather with water, but separates as a greasy scum, and not only is of no use itself for washing, but causes a waste of the alkali soap from which it is formed.

Spring water[*] is generally more or less hard, containing the carbonate or sulphate of calcium. Carbonate of calcium causes what is termed *temporary hardness* in water, by wasting soap. This salt is very little soluble in pure water, but can be dissolved in considerable quantities by water charged with carbonic anhydride. It can be removed, however, by boiling the water, as the carbonic anhydride is thus driven off, and the carbonate is then no longer soluble in the water, but is deposited on the bottom and sides of the vessel in which it is heated. This deposit is sometimes a very great nuisance in the boilers of engines, as it prevents the conduction of heat from the fire to the water. Dr. Clark has introduced a plan for removing the carbonate before the water enters the boiler at all. Hydrate of lime is added to the water in the tank from which the boiler is supplied. This deprives the water of its carbonic anhydride by forming with it carbonate of calcium, and therefore the carbonate which is in solution is deposited as well as that which is formed in the process.

Sulphate of calcium, however, if present, cannot be removed either by boiling or by hydrate of lime, and causes a *permanent hardness* of the water. It too becomes deposited on boilers, being slightly less soluble at the boiling point than at ordinary temperatures ; but it is not removed altogether, and is therefore a very troublesome cause of the waste of soap.

The so-called stearin candles are in reality made by removing the glycerin from the decomposed fats or oils, and consequently are not stearin, but stearic acid and other acids of fat, commonly called fatty acids. The glycerin is extracted in several ways; one is to form a calcium soap and remove the metal by sulphuric acid, a method employed chiefly on the Continent; another is to bring the fat in contact with steam at a high temperature, when the acid and glycerin separate and distil over, which is the process employed principally in the manufacture of Price's candles; a third method is to decompose the fat by sulphuric acid. The acids which are separated are purified and moulded into the required shapes.

CHAPTER XXIII.

WOOD — CELLULOSE — GUM — STARCH — SUGAR.

WOOD, as was remarked in the chapter upon carbon, consists of carbon, hydrogen, and oxygen, the two latter bodies being in the same proportion that they are in water. But there is this difference between wood and all the other compound bodies mentioned hitherto; it is neither a close uniform solid like silica in flint, nor a granular substance like dioxide of manganese, nor a crystalline body, like a salt; but it is composed of a fibrous substance, arranged in a great variety of ways, which forms a very beautiful object when a thin slice of wood is examined with a microscope. The substance which forms the basis of wood is called cellulose, and is found nearly pure in cotton, linen, and in the pith of the elder and the rice-paper plant, the hard portion of wood consisting of this substance mixed with resins, silica, or other substances incrusted on the walls of the cells of which wood is composed.

By far the greater part of trees and plants consists of cellulose; with the exception of the sap and of the colouring materials, the whole—bark, stem, leaves, and flowers—are mainly cellulose. A hyacinth growing in water is little else than cellulose filled in all its cells with water, the water furnishing the hydrogen and oxygen necessary for the growth of the plant, and the carbon coming from the carbonic anhydride of the air. Again, the framework of fruits is made of cellulose. The juice of an orange, for instance, is inclosed in thousands of little bottles, which consist chiefly of this substance; the husks of seeds, shells of nuts, and the stalks of grass and grain are mainly composed of cellulose.

Cellulose is one of the most important substances in the world to man, a great part of his clothing, namely, all cotton and linen goods, being composed entirely of this body, and paper, one of the great aids to civilisation, consisting of cellulose only.

Paper is usually made from rags, but is sometimes also made partly from esparto grass, and from the stalks of certain rushes which contain a very large proportion of cellulose. The rags are sorted, cleaned, and bleached by chlorine or by chloride of lime, and are then made into a pulp with water, which is caused to form a thin film over hot wire or flannel strainers. When the film is dry it forms blotting paper, and in order to render it fit to carry ink, it is coated with a mixture of alum and glue called *size*. Sometimes the size is mixed with the pulp, and then its composition is somewhat different.

When cellulose is steeped in a mixture of nitric and sulphuric acids it becomes converted into a remarkable substance called by chemists *pyroxylin*, and by others *guncotton*. The cellulose becomes nearly doubled in weight, and not much changed in appearance, but it will be found to have become explosive, much more so even than gunpowder, and may be kept in water for any length of time without losing its explosive character when dried. The change effected in the cellulose appears to be the substitution of nitric peroxide (page 26) for some of its hydrogen; and the products of the explosion are water-gas, carbonic anhydride, carbonic oxide, nitrogen, marsh gas, and nitric oxide; pyroxylin containing in itself, like gunpowder, all the necessary elements for its combustion. When guncotton is dissolved in a mixture of alcohol and ether, and the solution is allowed to dry by evaporation, the pyroxylin is left in a glutinous state and is then called *collodion*, a name derived from the Greek word for glue, a film of which is used by photographers for coating the glass plates upon which their pictures are intended to be taken.

If cellulose is heated with strong sulphuric acid it becomes converted into dextrin, a species of gum, and finally into sugar.

Starch is a body composed of identically the same elements in the same proportion as cellulose, but differs from that body in many ways. It exists in little grains or granules, which, when examined with a microscope, seem to have a little covering or envelope. Starch is not dissolved by cold water, but if it is boiled the granules absorb water, swell very much, and at last the envelopes burst and disappear, leaving the starch in the thick pasty condition in which it is used for stiffening linen. This is the reason why rice, beans, barley, &c., swell so much when they are cooked in water or milk.

Starch is very common in vegetables, and forms a large part of the food of man. Three-fifths of the flour of which bread is made consists of starch; most of the solid portion of rice and of the potato is starch, and it is found nearly pure in arrowroot, sago, and tapioca.

It may readily be obtained from wheat-flour by mixing the flour into dough and washing on a linen cloth with water, kneading it all the time. A milky fluid will run through the cloth containing starch in suspension, and if this is allowed to stand, the starch will settle at the bottom.

If dry starch is heated it becomes converted into dextrin, and if boiled with dilute sulphuric acid it becomes first dextrin and then sugar.

Dextrin, the substance known as *British gum*, is soluble in water, and is used by calico printers for mixing their colours, and by surgeons for making their bandages stiff and hard.

Sugar is another substance found in plants, especially the sugar-cane and sugar-beet, and also in the milk of animals. It too contains carbon, and hydrogen and oxygen in the proportions to form water, but the ratio of the carbon to the elements of water is not the same in sugar as in starch and dextrin. There are several varieties of sugar, of which the most important are *cane-sugar*, *milk-sugar*, and *grape-sugar*. Cane-sugar is contained in the juice of the sugar-cane, beetroot, sugar-maple, mallow, and in small quantities in fruit and honey, where it is mixed with grape-sugar and starch. It is the sweetest kind of sugar, and is, therefore, more highly prized than other sugars. To obtain the sugar from the canes, they are crushed between rollers, and the juice thus expressed is mixed with a little lime, which prevents fermentation, and concentrated, by boiling and evaporation, until the sugar crystallises, while the dark uncrystallisable syrup or *molasses*, consisting in great part of grape-sugar, is drained away. The raw crystals, commonly known as *brown sugar*, are refined by boiling with lime, and the syrup is filtered through animal charcoal to decolourise it, and is again crystallised. When allowed to crystallise undisturbed, sugar becomes a transparent solid, like glass, and if threads are suspended in the syrup, large and hard crystals form round them, constituting *sugar-candy*. To obtain *loaf-sugar*, in which the crystals are very small, the liquid is continually stirred while crystallising.

Sugar differs from starch in being very soluble in water, a pound of water dissolving, when cold, about three pounds of sugar. When heated gently, it melts, and on cooling becomes a transparent mass known as *barley-sugar*. If heated more strongly it becomes converted into *caramel*, a brown, nearly tasteless substance, which, under the name of *burnt sugar*, is used for colouring gravies and confectionary. If still more strongly heated, caramel gives off combustible gases, which burn and leave behind a porous mass of carbon.

Grape-sugar is found in large quantities in ripe fruits, and to a certain extent in the blood of animals. It is the sugar referred to on the last two pages as being formed when cellulose and starch are heated with sulphuric acid, and it may even be obtained in large quantities from rags or from sawdust, by treating them with oil of vitriol, that is, very strong sulphuric acid, and after some hours diluting the liquid with water and boiling for a considerable time. After the formation of the sugar, the sulphuric acid may be removed from the syrup by adding chalk to it, when sulphate of calcium is formed, which is insoluble and is therefore easily removed, and carbonic anhydride is given off. If starch is used instead of cellulose, the acid must be dilute.

The conversion of starch into sugar takes place in the seeds of plants while germinating, and in fruits whilst ripening, but at the same time dextrin is formed. This is due to the action of a peculiar body called *diastase*, about which very little is known, and the process is called *fermentation*.

A similar process takes place in the human body, whereby the insoluble starch of food is converted by a ferment in the saliva and other secretions of the body into soluble sugar, so that it may the more easily be taken up into the blood.

Though the chemist can convert cellulose into sugar, he cannot invert the process and reconvert sugar into cellulose. This is, however, performed by plants. Thus sugar-beet and turnip are sweetest when gathered early; if allowed to grow too long the sugar is converted into cellulose or woody fibre, and they therefore become tough and tasteless. So, also, if grass be left to grow too long, the starch and sugar turn to cellulose, and the hay is not so sweet and nutritious as it would have been if gathered earlier.

As was mentioned above, charcoal can be obtained from sugar by simply heating it; but a prettier way to do it is this: sulphuric acid has a strong affinity for water, and will extract the hydrogen and oxygen from sugar, which are there in the proportion to form water. Put a table-spoonful of strong syrup, made with loaf-sugar, into a tumbler set in a plate, and pour upon it a little good sulphuric acid. Considerable heat is produced, and the sugar blackens and froths out over the sides of the tumbler. When the tumbler is cool, turn the contents into the plate, and a good specimen is thus obtained of *sugar-charcoal*.

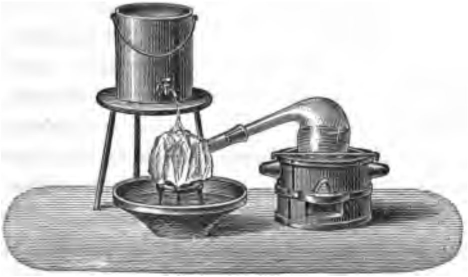
The action of ferments appears to depend upon a species of fungus which is present in them, and which must be alive in order to produce the effect. If the plant is killed by heating it excessively, the ferment loses its power of producing chemical change.

CHAPTER XXIV.

ALCOHOL — SPIRITS — WINE — BEER.

When a liquid containing grape-sugar, such as the juice of grapes, is brought in contact with the ferment known as *yeast*, it undergoes a change, whereby it loses some of its carbon and oxygen, which are given off as carbonic anhydride, and the remaining constituents remain combined, forming a new compound, alcohol. Grape-juice, if exposed to the air at a temperature somewhat below that of a summer's day, develops the ferment spontaneously, and is turned to wine. Wine, again, if further exposed to the air, develops another ferment within itself, and becomes converted to acetic acid or vinegar (page 84). The wine formed by the fermentation of sugar may be distilled, that is to say, boiled until it passes away in vapour, which is collected and condensed in a receiver kept cool by water trickling over it, as represented in Fig. 46; when the portion of liquid which first comes over will be, after filtering through animal charcoal, a tolerably pure solution of alcohol in water. By repeating

Fig. 46.



the distillation several times, the solution may be concentrated, as alcohol boils at a lower temperature than water, and consequently tends to come away in vapour before the water does. But as alcohol has a strong affinity for water, they cannot be entirely separated by this means. In order to obtain pure, or, as it is termed, *absolute alcohol*, the concentrated solution is mixed with quicklime, which has a still stronger affinity for water, and allowed to stand for several days. If this mixture be then distilled absolute alcohol is obtained.

It is a colourless volatile liquid, burning in air without depositing soot upon cold bodies, and with an acrid taste. It has never been frozen, and is therefore much valued for filling thermometers which are to be exposed to intense cold. It has, when diluted and taken in small quantities, a stimulating effect upon the nervous system, but does not afford nourishment to the body, nor does it, like oil and fat, serve, at least directly, to preserve animal heat; when taken in large quantities and concentrated it acts as a powerful poison.

Proof spirit contains about half its weight of alcohol, the remainder being water. The name is derived from the old method of proving the strength of spirit by moistening gunpowder with it and setting it on fire. If the powder was ignited the spirit was said to be *over proof*, but if the powder was left damp after the spirit had burned off it was called *under proof*.

Alcohol is the basis of all the wines and spirits in common use, the difference among them being due mainly to the various proportions of alcohol and to the flavour imparted by some essence which is either added or extracted in the process of manufacture. Brandy ought to be the spirit obtained from good wine by distillation, but too often it is only corn-spirit flavoured to imitate genuine cognac. Corn-spirit is obtained by distilling an infusion of fermented grain; when distilled with juniper berries it forms gin; when the fermented grain or *malt* has been dried, previously to being distilled, over a peat fire, whiskey is made. Rum is formed from fermented molasses; arrack is a spirit made from rice. None of these spirits are absolute alcohol, but are somewhere near the strength of proof spirit, the amount of absolute alcohol varying according to circumstances. Spirits when first distilled contain a very disagreeable oil, which has to be removed by several distillations, and the spirit then is said to be *rectified.*

In the manufacture of wine the grape-juice is allowed to remain in vats, where it undergoes fermentation spontaneously. If a sweet wine be desired, the process is stopped before all the sugar has become converted, a dry wine being formed when the process has completely transformed all the sugar of the grape. Effervescing wines, such as champagne, are formed by bottling them before fermentation has quite ceased, and, if they are intended to be sweet, adding cane-sugar to them. The amount of alcohol in different wines varies very much, port wine containing about a quarter of its volume of absolute alcohol, while Tokay contains only about a tenth of its volume. The strength of the wines in ordinary use come in the following order; Port, Madeira, Sherry, Claret, Burgundy, Champagne, Hock, Gooseberry.

When grape-juice is fermenting an acid substance known as *tartar* is formed, which consists principally of the tartrate of potassium. This substance is soluble in water but insoluble in alcohol, and consequently becomes deposited. The crust of old port wine consists chiefly of this substance, which has become deposited on the bottle in consequence of the gradual increase of the quantity of alcohol in the wine by slow fermentation after it is bottled and laid by. Other juices, such as currant or gooseberry juice, form similar substances when they ferment. But these are not so insoluble in alcohol as grape-tartar, and consequently make the wine taste sour. To prevent this sour taste, or rather to hide it, sugar is added, which however renders the wine liable to ferment and injures its quality.

Beer is an alcoholic liquor obtained from grain, containing a less amount of alcohol than wine. Grain, generally barley, is steeped in water until it is soft, then drained and spread out on a floor and allowed to germinate or grow. During the growth diastase is formed, and some of the starch of the grain is in consequence converted into sugar. After a day or two the grain is dried by heat, which also effects the conversion of the remainder of the starch, and it is then called *malt*. If the heat has not been very great the malt is pale in colour, and is used to make pale ale; if the heat has been considerable, some of the sugar is converted into caramel, and the malt is of a dark colour, and is used for making porter and stout. The malt is crushed and stirred up in a tub with water, and allowed to settle. The liquor, which is called *sweet wort*, is then boiled with hops in order to get a bitter flavour and prevent it from turning sour, and afterwards rapidly cooled. Yeast is then added, and it is allowed to ferment. Before however the change is complete, the yeast is separated, and the beer drawn off into casks, where the process of fermentation is continued very slowly, and the beer becomes stronger and less sweet.

CHAPTER XXV.

GLUTEN — ALBUMEN — CASEIN.

When, in chapter xxiii., starch was obtained by washing dough, a gummy substance was left on the cloth, which the water did not carry away. This substance is called *gluten*, and is composed of carbon, hydrogen, oxygen, and nitrogen. It is this body which gives firmness to bread, which, if gluten were not present, would be crumbling and brittle. For this reason, when cakes are made from rice, a certain proportion of flour is added, rice itself consisting chiefly of starch.

The water, too, which has run through the cloth with the starch, contains in solution another substance which it has obtained from the flour, and which may be made manifest by simply boiling the water after the starch which settles down has been removed. This substance is named *albumen*, and is identical in its composition with the white of egg, consisting of carbon, hydrogen, oxygen, nitrogen, and sulphur. The amount of it in flour is very small in comparison with that of the starch and gluten. Albumen exists in two forms or states, one of which is soluble in water, and the other insoluble. In eggs and in flour it is naturally in the soluble form, but is converted readily into the insoluble form by heat, when it becomes white and opaque instead of transparent, and tough and leathery instead of fluid. This change, which is called *coagulation*, is effected in the albumen of eggs which are cooked, and also in the albumen of baked bread, from which it cannot therefore be extracted by water as it can be from flour.

When moist, both gluten and albumen are liable to decomposition, the latter giving off as one of its products hydrosulphuric acid, as was mentioned on page 80.

The water from which the albumen has been abstracted by boiling contains a very small portion of grape-sugar and dextrin, which is not separated by the heat formed by the conversion of some of the starch in the grain from which the flour is obtained. This sugar is an important constituent of flour for making bread.

Bread is made by mixing flour with lukewarm water and a little salt, kneading it into dough with yeast; it is then set by for a time. The yeast causes the sugar to ferment, converting it into alcohol and carbonic anhydride, and the gas being given off in the interstices of the dough causes it to swell up and renders it porous. When the dough has *risen* sufficiently more flour is kneaded with it, and it is transferred to an oven, where the heat stops the fermentation by destroying the vitality of the yeast plant, and at the same time expands the gas and renders the mass still more porous and light. The alcohol which has been formed in the fermentation of the sugar is expelled by the heat of the oven, together with much of the water with which the dough was made. Some of the water is however retained, and swells the starch, which in the interior of the loaf is otherwise unchanged by the baking. The exterior of the loaf or crust becomes dry and hard, and is converted into a substance somewhat resembling caramel, or burnt sugar, the same which is formed on the outside of bread that is toasted.

Moist flour exposed to the air for some time generates in itself a ferment, and its starch becomes thus changed to sugar. This is *leaven;* and a small piece of such fermenting dough is capable of inducing similar fermentation quickly in larger quantities of dough, and was the material employed in ancient times for raising dough before yeast came into use. It is the substance referred to in Scripture, where it is said, "A little leaven leaveneth the whole lump."

The colour of brown bread is generally attributed to the presence in it of bran, or the husk of the corn. But this is not altogether the case. It depends partly too upon the fact that in inferior corn more of the starch has become converted into sugar than in that employed for making white bread, and the heat again converts the sugar into a species of caramel.

It is found that certain substances, for instance alum, tend to prevent this change in the sugar, and consequently they are often employed by bakers to keep the bread white, and make it appear as if it were made from the best flour, that is to say, from flour which contains only a little sugar.

Alum is considered by many to render the bread unwholesome, and it has been proposed to use lime-water, or hydrate of calcium instead, which has the same effect on diastase, and is not open to the same objection as alum.

Gluten is made up of two substances, one called *fibrin*, and the other called *gliadin*, the latter being the body which confers the sticky properties on gluten. The gluten obtained from different kinds of grain consists of different proportions of these substances, and the reason why wheat is preferred for making bread is, that it contains less gliadin than barley and other sorts of grain, and therefore not being so adhesive, rises better and forms lighter bread.

In order to do away with the difficulties experienced in keeping bread made in the ordinary way free from injurious substances, bread is now often made without fermentation at all. In one of these processes the water with which the dough is made is highly charged with carbonic anhydride under pressure, and the kneading is effected by machinery while the pressure is still continued on the gas in closed vessels. When the pressure is taken off, the gas escapes, and causes the dough to swell and become porous, just as it does when liberated by fermentation, and the dough is then ready for baking. Bread made in this way is called *aërated bread*, and though sometimes not preferred to ordinary bread, has the advantages of cleanliness (as kneading with the hands or feet is thus avoided), as well as of purity and wholesomeness.

Milk is a mixture consisting chiefly of water, fat, and oil, sugar, and casein. The fat and oil of milk separate in a great measure if milk is allowed to stand, rising up to the top as *cream*, from which *butter* is made by churning or beating it so as to break up the little envelopes which enclose the fat when it is in the state of cream.

If, after the cream has been separated from it, milk be gently warmed, and a little dilute acid, or rennet, which is an infusion of the stomach of the calf, be added to it, it divides into two portions; one, solid, contains coagulated casein, and is called *curd;* the other, liquid, contains the milk-sugar and other constituents of the milk dissolved in water, and is termed *whey*. Cheese is made from the curd by removing it from the whey, and subjecting it to pressure, after which it is put by to ripen. In the process of ripening the casein undergoes a kind of fermentation which confers upon it the characteristic flavour and smell of cheese.

The milk-sugar of the whey is, like grape-sugar, subject to fermentation, forming alcohol and a peculiar acid called lactic acid. It is lactic acid which gives the taste to sour milk; and when butter has not been thoroughly washed it is also liable to become rancid, from the presence of some of this fermentable sugar which it has carried with it from the milk.

CHAPTER XXVI.

CHEMISTRY OF LIFE.

LIVING beings are generally divided into two great classes, *plants* and *animals;* and although in some cases the two classes approach so near to one another that it is difficult to draw an exact line between them, still, taken generally, they present remarkable differences, as well as remarkable analogies. Living things are continually growing—that is to say, they are constantly obtaining fresh matter or food from the world outside them, and making it part of themselves. If this process be stopped for a short time by any means, they lose the power of assimilation, as it is called, altogether, and gradually become broken up and decomposed; in other words, they die. In plants, when once matter has been assimilated and deposited, it remains until the death of the plant; but in animals there is just as continually absorption and destruction of deposited matter, as there is assimilation of fresh matter; and, partly on this account, animals do not grow to the same size as plants, and require more food to preserve their life. Besides the material required for the formation of their tissue, another thing is necessary for the life of plants and animals, and that is, a proper temperature. If the living creature is heated or cooled too much, the assimilation of food is stopped, and it dies.

The body or frame of plants consists in the main of carbon, hydrogen, and oxygen, in the form of cellulose, to which are added silica and other substances to confer upon it hardness, or perfume, or some other property special to an individual plant. The formation of cellulose in plants appears to depend upon the presence of a substance identical in composition with albumen, but differing from it in the circumstance that it possesses the remarkable property of reproduction, which ordinary albumen has not. How this substance effects the building up of cellulose from its elements is not at all understood; but its presence seems to be always necessary to the formation of the tissues of living beings, and it has therefore received the name of *protoplasm.*

The nitrogen of protoplasm is furnished originally by the gluten in the seed, but is supplied afterwards by ammonia and other nitrogenous substances absorbed by the plant from the air and soil by which it is surrounded.

The bodies of animals, on the other hand, consist essentially of substances composed of the same materials as those which form cellulose, but with nitrogen in addition; and the main difference between their assimilation of food and that of plants, lies in the circumstance that they are unable to form their tissues from the elements as they find them in the world outside, until they have first been partially at least built up for them by plants. But it is remarkable that neither plants nor animals seem ordinarily able to assimilate any elementary substance, with the single exception of oxygen, unless it is in a combined form.

The food of living creatures has, then, two objects—one the building up and repair of the tissues, the other the maintenance and regulation of a proper temperature in those tissues. The former is performed by the assimilation or conversion of the food into tissue under the influence of protoplasm; the latter is effected by the balance, on the one hand, of the heat produced by the chemical change of the food into the more complex tissue, with, on the other hand, the cold produced by evaporation of water from the exterior of the body, and the loss of heat which is experienced when the tissues are broken up and changed from complex to more simple bodies. Other circumstances, too, influence the temperature of living creatures, such as the external air, and, in the case of animals, movement and locomotion; but these may be left out of consideration for the sake of simplicity, as of course it is possible that a living being may live always in an atmosphere of the same temperature and never move. In that case, the only motion will be the circulation in the tissues of the sap or blood, which will tend to produce a slight loss of heat.

Both of these objects might be accomplished by the same food, provided that the chemical change of the food into tissue supplied the necessary amount of heat; and in the case of vegetables and of some animals this is approximately the case.

Plants, then, to form their tissues, require carbon, hydrogen, and oxygen, together with a certain amount of nitrogen to make their protoplasm. Carbon is furnished to them by the atmosphere in the form of carbonic anhydride, while the hydrogen and oxygen are supplied in proper proportions by the soil in the form of water. Both the carbonic anhydride and the water are absorbed, the former by the leaves, the latter by the roots of the plant, the process of absorption being something akin to the *osmose*, described on page 89.

Nitrogen is supplied to the leaves, too, in the form of ammonia, by the atmosphere, and in larger quantities, in the form of nitrates and salts of ammonium, by the soil to those plants which, like corn, produce a large amount of nitrogenous matter in the form of gluten.

Carbonic anhydride, then, and water, together furnish materials for making cellulose; but cellulose being formed of carbon, and of hydrogen and oxygen in the proportions to form water, the oxygen which the carbon brings with it is not wanted — it is in excess. The leaves, therefore, give it out again into the atmosphere, so that a plant breathes in carbonic anhydride and breathes out oxygen. Though cellulose is eventually formed in the plant, the first products of the union of the carbon, hydrogen, and oxygen are dextrin and sugar. The advantage of this is that cellulose is insoluble in water, and, consequently, where it is formed, there it must stay in the plant; the water in the sap would not dissolve it and carry it about. But dextrin and sugar are soluble; they circulate, then, in the sap, and are converted into cellulose in those parts of the plant where they are needed. The difference in the composition of sugar and cellulose is merely that sugar contains less hydrogen and oxygen in the proportion of water than cellulose, while dextrin and cellulose have the same percentage composition.

The formation of dextrin and sugar is effected principally in the leaves of plants, where the ascending sap, consisting of water with certain substances in solution, comes in contact with carbonic anhydride, and is converted under the combined influence of sunlight and the nitrogenous substance in the green colouring-matter of the leaves. The converted, or, as it is termed, *elaborated* sap then descends, carrying material ready to form cellulose into other parts of the plant.

This formation of sugar and its circulation in the sap are very manifest in the case of the sugar-maple. The tree is tapped a short distance above the ground at the time of year when the sap is rising, and the juice which runs off is collected and furnishes a considerable quantity of sugar.

Plants also effect a storage of material which can be used when required for the formation of new tissue, and this they do in the form of starch. Starch is eminently fitted for the purpose, because, being insoluble in water, it is not carried away in the sap, and yet, when wanted, is easily converted into soluble dextrin and sugar by the influence of diastase. This is what occurs in the germination of seeds; the gluten or albumen in them form diastase, which ferments the starch, converting it into dextrin and sugar. As the growth proceeds, the dextrin and sugar are turned into cellulose, and thus furnish new material for the growth of the plant.

Plants contain gluten and albumen in all their tissues in more or less quantity, but the amount in the seeds is much greater than that in the rest of the tissues, and this is the very place where it is most required, for there is stored the material for the formation of a fresh plant, which is begun by the production of a ferment from the decay of the gluten. Those plants which, like corn, form a large proportion of gluten, require a soil possessing more nitrogen than usual, and this explains the good effect upon such plants of manures which contain ammonia or some other compound of nitrogen.

The albumen of many plants contains, besides the elements already mentioned, a small proportion of sulphur and phosphorus, which is obtained from the soil. If the soil be deficient in these materials they must be added, just as nitrogen is. This is why sulphates and phosphates are sometimes applied to land upon which grain is to grow.

Animals obtain the elements of their tissues from plants, and therefore it is convenient, from an animal's point of view also, that gluten and albumen should be stored up in the seeds.

The tissue which is essential to animals contains nitrogen, carbon, hydrogen, and oxygen, in the same proportions in which they exist in gluten and albumen, and therefore, as was remarked before, it is possible to conceive that an animal might live entirely on these two products of plants if his temperature were not lowered in any way. But inasmuch as the tissues of animals are constantly decaying, that is, are broken up from complex into more simple substances, they are always liable to a lowering of their temperature. For, as a rule, the combination of elementary bodies involves a development of heat; and, inversely, the resolution of a compound body into its elements is attended by an absorption of heat. For example, the combination of oxygen with carbon is the cause of the heat of an ordinary fire, while, on the other hand, it is necessary to supply heat to the compound dioxide of manganese in order to obtain the element oxygen from it.

For this reason animals require other kinds of food, which, by their combination in the body, may produce the heat needful to keep up the temperature of their tissues.

This they can obtain in the form of starch from vegetables, and of oxygen from the air. Like plants, animals are furnished with two absorbing organs, the stomach performing the functions of the roots of plants, the lungs those of the leaves.

Starch is an insoluble substance, however, and it must be rendered soluble before it can be absorbed and burnt. This is effected by the spittle of the mouth and the juices of the stomach, which convert starch into sugar during mastication and digestion, in the same way that diastase effects the conversion in plants. The sugar is then absorbed and conducted into the tissues, where it is again converted, before it is finally burnt, into fat, carbonic anhydride, water, and oxygen.

Oxygen is also absorbed in the lungs and carried by the blood (which answers to the sap of plants) into all parts of the body, where it meets the fat and oxidises its carbon. The carbonic anhydride resulting from this combustion, and from the decomposition of the sugar mentioned above, is again taken up by the returning blood and carried to the lungs, where it is given out. So that the leaves of plants and the lungs of animals perform exactly opposite functions; leaves absorb carbonic anhydride and give out oxygen, while lungs absorb oxygen and give out carbonic anhydride. Thus plants and animals supply each other with the breath necessary for each of them, and in this way become mutually dependent upon each other for their lives.

This is also exemplified in another way. Plants assimilate nitrogen as nitric acid and ammonia; while, on the other hand, animals produce, by the destruction of their tissue, nitrogenous bodies, and throw them away, so that plants are again able to appropriate them.

Animals that live in cold climates, and whose temperature is consequently lowered more than that of animals in warm climates, find that the fat supplied by starch does not give them sufficient heat by its combustion, and therefore they are in the habit of providing themselves with extra fuel ready made, by eating fat and oil.

Animals differ from plants in requiring a constant supply of tissue-forming material, and therefore they do not store it up to the same extent; but they do store up heat-producing material, namely, fat, and that very often in large quantities.

Besides the substances mentioned above, many animals as well as plants require mineral foods in order to build up their skeleton, or to serve some other purpose essential to their well-being if not to their life. Thus, phosphate of calcium is an important constituent of bones, giving them hardness and strength, and phosphorus in another form seems to be necessary to the brain in order that it may properly perform its duties.

One of the most important foods of plants and animals is water, which is required not only to dissolve the materials, but also to form part of the new tissues themselves. Cellulose has been seen to consist of carbon combined with the elements of water, and starch differs from grape-sugar only in containing less hydrogen and oxygen in the proportion of water.

The above is only a rough outline of the chemistry of life; but in considering such a complicated structure as the body of man, or of the higher animals, it is obvious that many hundred variations and additions would be rendered necessary to furnish anything like a complete account of the chemical processes involved. The chemistry of the elements, considered with regard to the dead structures on the earth, such as minerals, gases, &c., bears about the same relation in point of importance and interest to the chemistry of life, that the alphabet of a language bears to its grammar. The idea may even be carried a step farther, and physiology, the science which treats of the functions or duties of the several organs and parts of living creatures, may be called the literature.

The great lesson to be learnt from chemistry is, that although the matter of which the world is composed is constantly being changed in form, nothing is destroyed. When things burn, as we express it, there is no destruction, but merely change from one form to another, and what seems to vanish soon reappears in the solid forms growing up around us. So, when decay takes place, there is no loss of a single particle of matter, there are only chemical changes forming new combinations and arrangements of the particles of the decaying substance. Chemistry is at work everywhere, not destroying, but taking to pieces only to rebuild again, and it does the latter quite as readily and rapidly as it does the former.

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